Caridean Shrimp

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Introduction

Caridean shrimp are an important component of the San Francisco Estuary's aquatic resources. They are a food source for many species of fish, crabs, and marine mammals and support a commercial fishery in the estuary. Shrimp are omnivores and prey upon a variety of organisms and plant material. Because of their numerical abundance and position in the food web, they play an important ecological role in the estuary. The San Francisco Bay Study collected 15 species of caridean shrimp from 5 families in the San Francisco Estuary from 1980 to 1996 (Table 1). Because we did not sample rocky habitats or vegetated areas, such as eelgrass beds, this is not a complete list of all species present in the estuary. The 6 most common species of shrimp, *Crangon franciscorum*, *C. nigricauda*, *C. nigromaculata*, *Heptacarpus stimpsoni*, *Palaemon macrodactylus*, and *Lissocrangon stylirostris* are the focus of this chapter. The 4 species of *Crangon* and *H. stimpsoni* are native, but *P. macrodactylus* was accidentally introduced to the estuary from the Orient in the 1950s (Newman 1963).

Table 1 Caridean shrimp catch from the otter trawl, by year, from 1980 to 1996. All surveys and stations sampled are included.

	Year																	
Species	*80*	*81*	*82*	*83*	*84*	*85*	*86*	*87*	*88*	*89*	*90*	*91*	*92*	*93*	*94*	*95*	*96*	*80–96*
Betaeus longidactylus				5		3		1		1	3	6			1			20
Betaeus spp.								1	6		1			2				10
Crangon franciscorum	156466	99029	278402	235743	233313	50763	212716	146024	95814	89151	57732	63831	24656	78464	60093	130387	235881	2248465
Crangon munitella					2	1		1			1	14		1	2		4	26
Crangon nigricauda	25054	11784	7924	16233	6304	8554	26901	50787	75385	52695	79577	92292	70597	60068	53710	35229	77094	750188
Crangon nigromaculata	977	297	562	7149	2884	1233	3568	6785	9552	6307	16931	24579	26759	30440	21196	16656	21429	197304
Exopalamon carinicauda																1		1
Heptacarpus spp.	1																	1
Heptacarpus brevirostris	1			2												3		6
Heptacarpus palpator				1														1
Heptacarpus pictus			6															6
Heptacarpus stimpsonii	1665	574	724	972	1093	1391	1424	5307	5954	8878	8247	16835	7858	8471	6000	4495	9499	89387
Heptacarpus taylori	10			1				1		1	1	1						15
Lissocrangon stylirostris			1	2	1245	333	2100	856	103	32	214	89	43	560	169	933	1010	7690
Lysmata californica					1													1
Palaemon macrodactylus	6165	6376	3282	896	7958	4181	4185	3070	2491	5332	4640	5935	5040	4298	2894	3410	3338	73491
Pandalus danae	1		1	1	1	1	5	8	1	2		2	2		5	4	31	65

Crangon spp. are commonly referred to as "bay shrimp" and *P. macrodactylus* as "pile shrimp"; collectively they are often referred to as "grass shrimp." These species (primarily *C. franciscorum*) are fished commercially by trawlers in the San Francisco Estuary and are currently sold as bait to sport anglers. Since 1980, this fishery has landed between 100,000 and 200,000 pounds per year, although landings approached 3 million pounds per year in the late 1920s and 1930s when bay shrimp were sold for human consumption. From the late 1980s through the early 1990s, the fishery was concentrated in the Alviso Slough and Redwood Creek areas of South Bay. Shrimp were probably abundant in these areas because of the lower salinity water present all year in the vicinity of several sewage treatment plant discharges. Occasionally commercial fishermen are not able to meet demand because of a scarcity of large shrimp suitable for bait (P. Reilly, personal communication, see "Notes").

The life cycles of Crangonidae and Palaemonidae that inhabit shallow coastal waters and estuaries are similar, and they migrate seasonally in response to salinity, temperature, and maturity or life stage (Allen 1966). For example, most *C. franciscorum* larvae hatch in winter and early spring in Central Bay or the Gulf of the Farallones from eggs carried by the females. Post-larvae and juveniles migrate upstream to lower salinity, warmer areas, such as San Pablo and Suisun bays, to rear through the summer. Adult shrimp migrate downstream in fall and winter to higher salinity, cooler waters to complete the life cycle.

All the species included in this report use the estuary as a nursery area, but in varying degrees. They have a slightly different timing of larval hatching and juvenile recruitment to the estuary and use different nursery areas based partly on salinity and temperature preferences (CDFG 1992). All have a short life span—male *Crangon* are generally reported to live for 1 to 1.5 years and females 1 to 2 years, with females growing to a larger size than males. However, *C. franciscorum* has been reported to be a protandrous hermaphrodite, with males transitioning to females at approximately 1 year (Gavio 1994).

All species of shrimp common to the estuary are undoubtedly opportunistic feeders, with diet varying by location and size. For example, *C. franciscorum* from Suisun Bay and the western delta primarily preyed upon *Neomysis mercedis* (Sitts 1978, Siegfried 1980). But in San Pablo Bay, where *N. mercedis* is usually not common, amphipods, bivalve, polychaetes, and isopods dominated the diet of *C. franciscorum* (Wahle 1985). Prey also varied with size: smaller *C. franciscorum* (<30 mm total length, TL) consumed mostly foraminiferans, ostracods, and copepods; intermediate size shrimp consumed mostly amphipods and bivalves; and larger shrimp (>60 mm TL) consumed mostly bivalves, caridean shrimp, and polychaetes (Wahle 1985).

Caridean shrimp are preyed upon by many fishes in the estuary, including striped bass (Johnson and Calhoun 1952, Ganssle 1966), staghorn sculpin (Ganssle 1966, Boothe 1967, Kinnetic Laboratories and Larry Walker Associates 1987), green sturgeon, white sturgeon, brown smoothhound, and Pacific tomcod (Ganssle 1966). They are also consumed by harbor seals and several species of diving ducks (Cottam 1939, Yocom and Keller 1961, Vermeer 1982).

Crangon franciscorum

Crangon franciscorum, the California bay shrimp, is a euryhaline species that is the dominant caridean shrimp in most Pacific coast estuaries (Emmett and others 1991) and the most common species in the San Francisco Estuary (Schmitt 1921, Bonnot 1932, Israel 1936, Ganssle 1966, Hatfield 1985, CDFG 1992). It ranges from southeastern Alaska to San Diego, California (Rathbun 1904), and has been collected from the intertidal to 91 m (Jensen 1995). In the San Francisco Estuary *C. franciscorum* is usually found from South to Suisun and Honker bays, but has been collected as far upstream as the San Joaquin River at Middle River (Israel 1936). Juveniles prefer shallow (<5 m), low salinity waters and migrate to deeper, higher salinity waters as they grow (Israel 1936). A maximum size of 110 mm TL had been reported from the

Columbia River (Emmett and others 1991), but the largest reported sizes from the San Francisco Estuary are 82 mm TL for females and 62 mm TL for males (Israel 1936).

In the San Francisco Estuary, the reproductive season extends from December through June, although some ovigerous females have been collected in all months (Israel 1936). Ovigerous females migrate to higher salinities and in most years they are concentrated in the nearshore ocean area rather than in the estuary (Hatfield 1985). In Yaquina Bay, Oregon, reproduction is bimodal, with older females reproducing from December to March and first time and repeat breeders reproducing from April to August (Krygier and Horton 1975). Ovigerous females were concentrated in the lower portion of Yaquina Bay and adjacent coastal waters, and none were collected at salinities <14.6‰ (Krygier and Horton 1975). Larvae hatch in 10 to 12 weeks in the spring and 8 to 10 weeks in summer. In the laboratory, *C. franciscorum* usually passed through 7 larval stages, although some larvae metamorphosed after only 5 stages. Larvae developed to post-larvae in 14 to 20 days at 20 °C, but at typical estuary or ocean temperatures larval development probably takes 30 to 40 days (Mondo 1980).

The minimum time to reach maturity and life span of *C. franciscorum* varies by location and study. In Yaquina Bay, Oregon, *C. franciscorum* mature within 9 to 12 months from hatching; males mature at 34 mm TL and live to 1 year and females mature at 48 mm TL and live to 1.5 years (Krygier and Horton 1975). In the San Francisco Estuary, male *C. franciscorum* mature at 37 mm TL, females at 53 mm TL, and both sexes live 1 year (Israel 1936). But Kinnetic Laboratories (1987) reported males to live to 1.5 years and some females to 2.5 years in the estuary. Alternatively, if *C. franciscorum* is indeed a protandrous hermaphrodite, males transition to females at approximately 1 year and could live to 2 to 2.5 years as females (Gavio 1994). This life history strategy would account for the apparent shorter life span and smaller size of males reported by previous researchers.

Methods

Juvenile *Crangon franciscorum* were separated from adults based on a size of maturity of 37 mm TL for males (Israel 1936, CDFG unpublished data) and 48 mm TL for females (approximately 1% of the ovigerous females we collected were <48 mm). Juvenile and adult categories were used for the abundance and distribution analyses, while 5 mm size groups by sex were used for the salinity and temperature analyses. The annual index periods selected were May through October for juveniles and February through September for adults. The February through September index period omitted months when there was often a high abundance of adult *C. franciscorum*, but was necessary for the inclusion of the 1989 to 1994 data in the annual analyses. For analysis of seasonal distribution patterns, 1983 and 1988 were selected as representative high and low outflow years for both juvenile and adult *C. franciscorum*. Length frequency data from 1988 were used to demonstrate the typical monthly length frequency distributions. All sizes reported are total length.

Results

Length Frequency

Crangon franciscorum is the largest common shrimp species in the estuary. This study collected females to 87 mm and males to 68 mm. Adult shrimp usually dominated our catches from January through March; in 1988 several cohorts of adult females were collected in January and February, but by March, only 1 cohort was detectable in the length frequency histograms (Figure 1). This adult female cohort continued to be collected at least through September, but the adult male cohort essentially disappeared from our catches after April 1988.

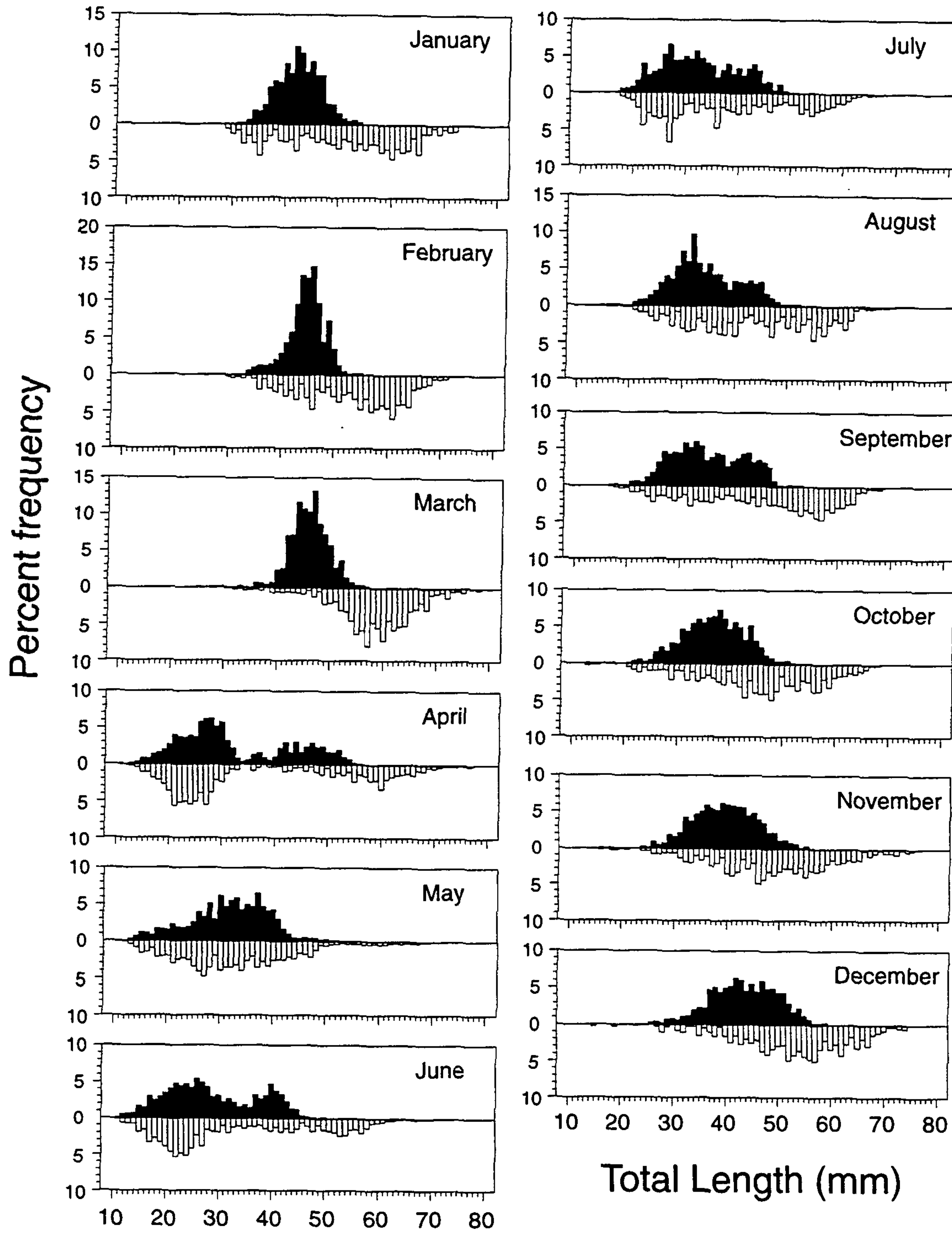

Figure 1 Monthly percent length frequencies of male (closed bars) and female (open bars) *C. franciscorum* **collected with the otter trawl in 1988.** Size classes are every 1 mm, from 11 to 80 mm.

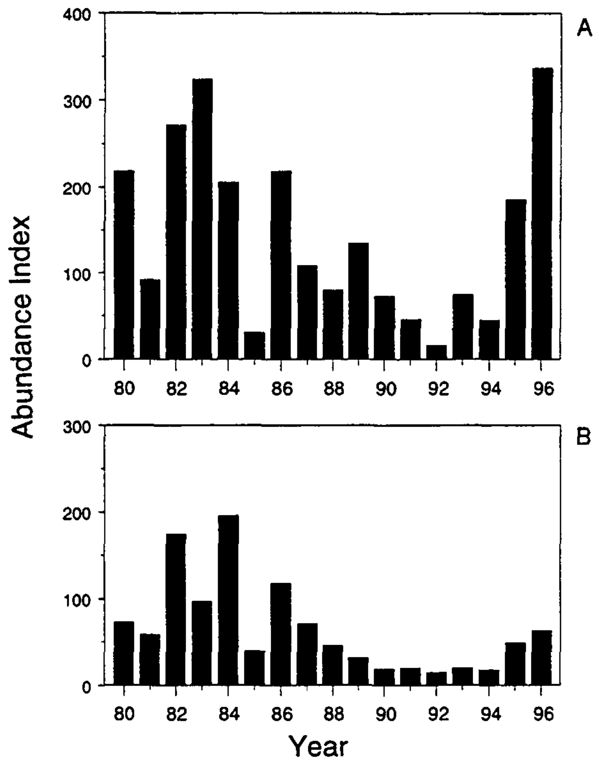

Figure 2 Annual abundance indices of *C. franciscorum* collected with the otter trawl: (A) juveniles (1980 to 1996), the index period is May to October and the indices are divided by 1000; (B) adults (1980 to 1996), the index period is February to September and the indices are divided by 1000

Often, multiple juvenile cohorts were collected in spring and early summer; in 1988, the first cohort was collected in April and a second cohort appeared in June. By late fall these multiple cohorts were difficult to distinguish and many shrimp were mature or approaching maturity. By December, the male modal length was about 40 mm and the female modal length was about 50 mm.

Abundance

Crangon franciscorum was the most commonly collected species of caridean shrimp over the study period and was the most common species in all years except from 1990 to 1992, when it ranked 2nd to *C. nigricauda* (see Table 1). The annual abundance of juvenile *C. franciscorum* varied by a factor of almost 20 from 1980 to 1996 (Figure 2A, Table 2). The highest annual index was in 1996, followed closely by 1983 and 1982. The lowest indices were in 1985 and 1992 and there was a general trend of declining abundance during the 1987–1992 drought.

The annual abundance trend of adult *C. franciscorum* either mirrored the juvenile trend or had a 1 year lag. The highest indices were in 1982 and 1984 and the lowest indices were in 1985 and from 1988 through 1994 (see Figure 2B, Table 3). A strong year class of juveniles resulted in a relatively large number of adult shrimp in the estuary in winter and spring of the following year.

Table 2 Monthly and annual abundance indices of juvenile *C. franciscorum* collected with the otter trawl from 1980 to 1996. The index period is May to October and the indices are divided by 1,000.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*May–Oct*
1980		2	1	1	44	378	166	294	320	113	39	26	219
1981	3	8	4	9	101	72	159	47	152	19	11	5	92
1982	5	2	1	146	318	478	175	328	230	105	72	76	272
1983	110	40	43	28	5	422	834	269	195	220	355	181	324
1984	55	15	34	101	175	488	200	184	78	111	8	19	206
1985	4	3	1	0	20	57	41	40	19	8	3	1	31
1986	1	0	0	0	56	236	294	367	286	72	43	31	219
1987	18	10	10	15	68	140	233	104	62	46	18	6	109
1988	6	4	1	21	89	154	156	52	22	7	5	2	80
1989	3	1	1	11	151	141	161	86					135
1990		2	1	3	71	123	115	74	41	13			73
1991		5	1	1	8	58	87	60	42	21			46
1992		3	1	1	19	28	23	14	7	5			16
1993		0	0	4	111	122	111	65	30	13			75
1994		0	0	3	34	65	65	62	36	12			45
1995	1	0	1	3	148	283	218		235	46	19	17	186
1996	9	8	7	25	427	753	483	254	74	31	17	11	337
1981–1988, 1996	24	10	11	38	140	311	286	183	124	69	59	37	

Strong seasonal trends in the abundance of juvenile and adult *C. franciscorum* occurred in the estuary. Juvenile abundance was strongly unimodal with a single peak from May through September in most years (Figure 3, see Table 2). In any given year, the period of peak abundance extended from 3 to 5 months, depending on the relative size and timing of the cohorts (see Table 2). Small fall cohorts occurred in several years, and in 1983 there was a large fall cohort with an abundance peak that extended through December.

Adult *C. franciscorum* abundance was bimodal; peaks occurred from November through March and from May through September (see Figure 3, see Table 3). The largest winter-spring peaks occurred in years following high juvenile abundance (1981, 1983, 1984, and 1987) and the smallest winter-spring peaks occurred in years following low juvenile abundance (1982, 1986, 1989, and 1985). There was no distinguishable summer-fall abundance peak of adults in either 1983 or 1992.

Distribution

Adult and juvenile *C. franciscorum* were widely distributed throughout the estuary, although they were more commonly collected in the northern reach (San Pablo Bay through the west delta) than in South and Central bays. The center of distribution of juvenile *C. franciscorum*, on an annual basis (May to October), ranged from San Pablo Bay to the west delta (Figure 4). In 1983 and 1995, the highest CPUE was in San Pablo Bay. In 1988 and from 1990 through 1992, CPUE was highest in the west delta area, and in all other years highest in Suisun Bay. The average CPUE was very low in San Pablo Bay in low outflow years and low in the west delta in high outflow years.

The center of distribution of adult *C. franciscorum* also varied annually, but not as much as for juveniles. In high outflow years (for example, 1982, 1983, 1986, and 1995), the highest annual CPUE (February though September) was in San Pablo Bay and in low outflow years (for example, 1981 and 1987) the highest annual CPUE was in Suisun Bay (Figure 5). Although the distribution of adult *C. franciscorum* was broadest in years with low outflow, CPUE was never highest in the west delta as it was for juveniles.

Table 3 Monthly and annual abundance indices of adult *C. franciscorum* collected with the otter trawl from 1980 to 1996. The index period is February to September and the indices are divided by 1,000.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Sep*
1980		44	25	8	8	68	93	114	221	129	53	82	73
1981	92	70	41	46	51	15	53	33	153	41	25	48	58
1982	53	34	23	8	170	253	346	360	208	110	88	136	175
1983	227	171	154	93	69	89	84	68	46	124	163	133	97
1984	103	140	534	164	134	427	102	43	23	23	14	48	196
1985	47	143	21	14	7	34	54	28	18	11	9	15	40
1986	27	15	7	9	18	44	273	293	285	70	171	109	118
1987	82	119	74	33	198	47	44	23	33	29	36	60	71
1988	51	50	24	24	29	82	88	52	22	9	13	15	46
1989	23	12	17	14	27	51	63	43					32
1990		19	28	16	11	14	29	22	13	10			19
1991		25	15	11	10	17	20	26	35	23			20
1992		36	34	10	8	7	9	5	8	7			15
1993		4	6	3	5	18	58	46	24	14			20
1994		12	12	3	7	25	21	34	29	13			18
1995	16	41	25	11	13	76	95		79	25	38	80	49
1996	101	49	81	56	29	72	74	85	58	17	42	52	63
1981–1988, 1996	87	88	107	50	78	118	124	109	94	48	62	68	

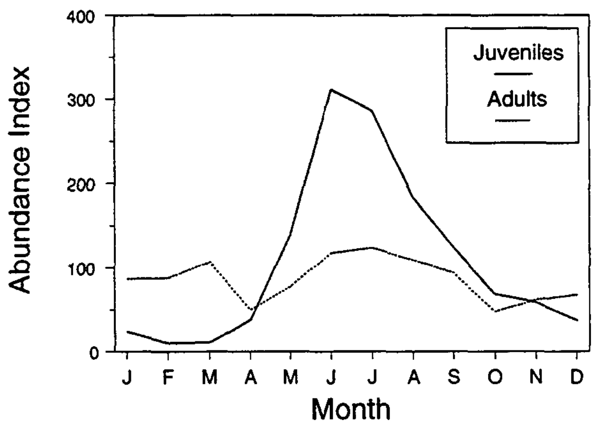

Figure 3 Monthly abundance indices of juvenile and adult *C. franciscorum* collected with the otter trawl from 1981 to 1988 and in 1996. The indices are divided by 1000.

There were strong seasonal trends in the distribution of juvenile and adult *C. franciscorum* in the estuary. In 1983, a "wet" year, the center of distribution of juveniles was in San Pablo Bay from January to July, shifted to Suisun Bay in August and September, and shifted back to San Pablo Bay for the remainder of the year (Figure 6). This general pattern of an upstream distribution shift occurred in all years, although the initiation and extent of the upstream movement varied with freshwater outflow. For example, in 1988, a "critically dry" year, the center of distribution shifted from Suisun Bay to the west delta in March and essentially remained there for the rest of the year (Figure 7).

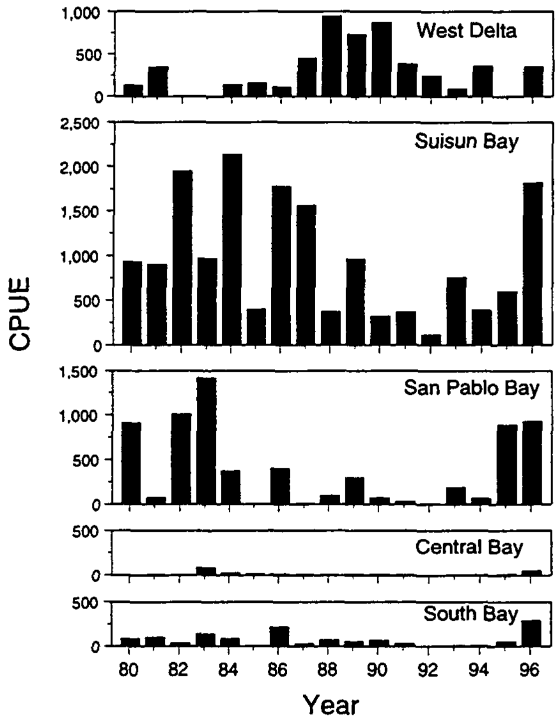

Figure 4 Annual distribution (CPUE) of juvenile *C. franciscorum* for May through October from 1980 to 1996

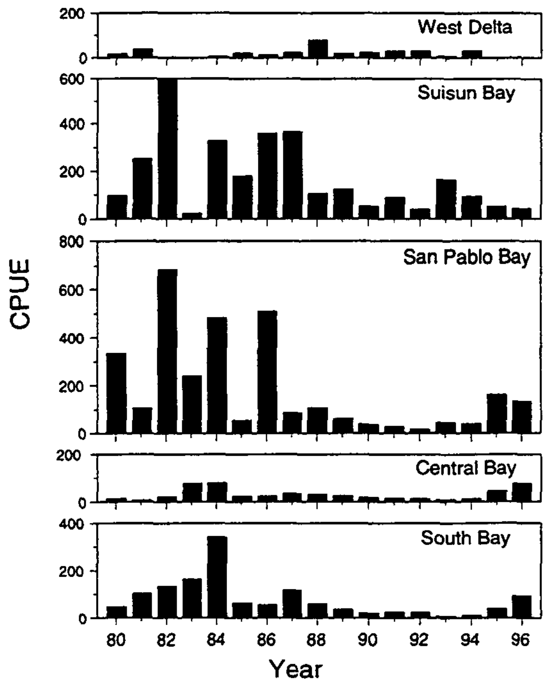

Figure 5 Annual distribution (CPUE) of adult *C. franciscorum* for February through September from 1980 to 1996

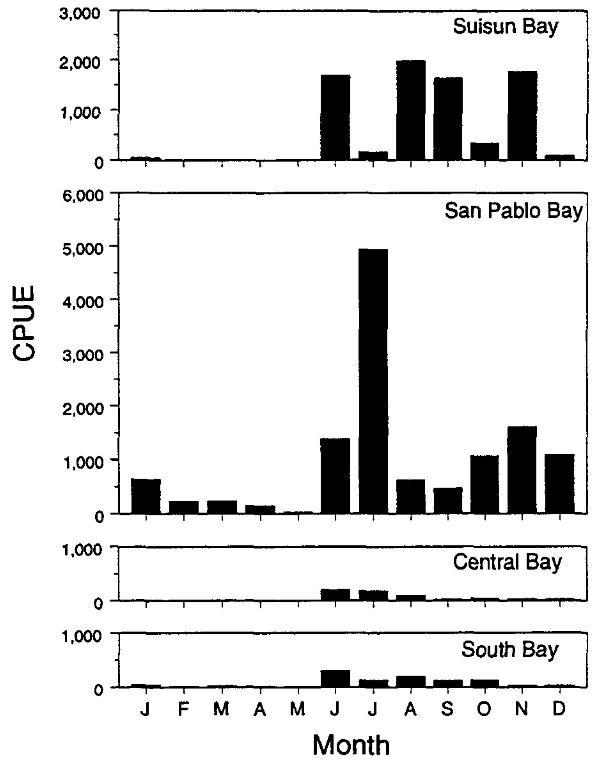

Figure 6 Monthly distribution (CPUE) of juvenile *C. franciscorum* in 1983

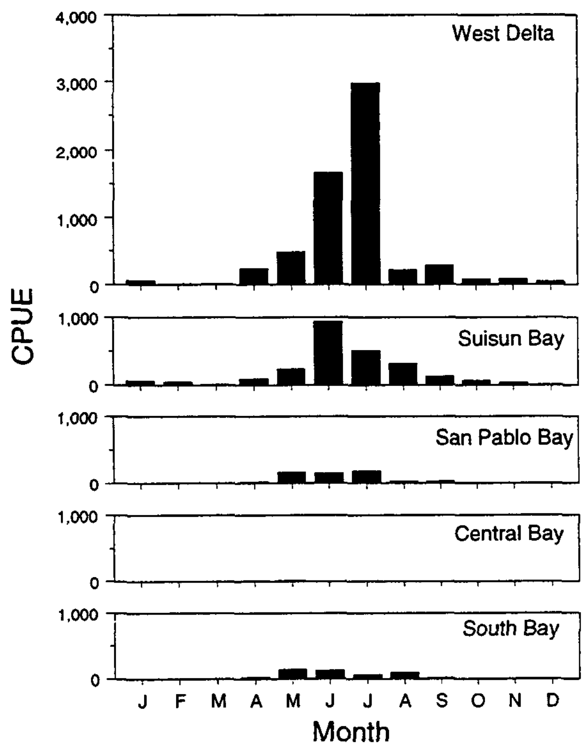

Figure 7 Monthly distribution (CPUE) of juvenile *C. franciscorum* in 1988

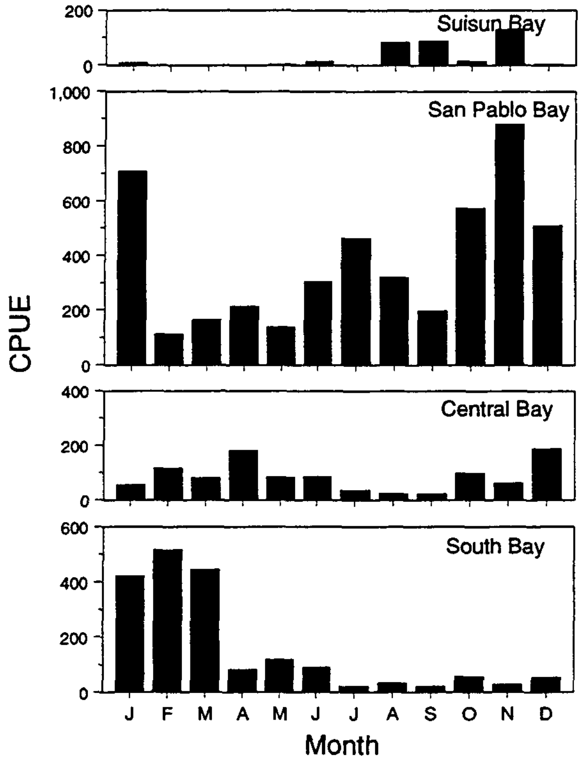

Figure 8 Monthly distribution (CPUE) of adult *C. franciscorum* in 1983

Although adult *C. franciscorum* also moved upstream seasonally, the extent and timing of this movement differed from the juvenile movement. For example, in 1983, adult distribution was centered in San Pablo Bay in January (Figure 8), shifted to South Bay in February and March when outflow increased (see Introduction chapter, Figure 2), and moved back to San Pablo Bay in April as outflow decreased. The highest CPUE was in San Pablo Bay through the remainder of the year, although it did increase in Suisun Bay in late summer and fall. In 1988, a year with much lower outflow than 1983, the adult distribution was initially centered in San Pablo Bay but shifted to Suisun Bay in March (Figure 9). Although CPUE was highest in San Pablo Bay in May and June, the center of distribution again shifted to Suisun Bay in July and to the west delta in November and December.

Salinity and Temperature

Crangon franciscorum was collected over a wide range of salinities (Figure 10A); the mean salinity was 13.9‰, with 90% collected between 2.8‰ and 25.9‰ (10th and 90th percentiles, respectively). It was also collected at relatively warm temperatures (Figure 10B); the mean temperature was 18.2 °C with 90% collected between 13.2 and 21.3 °C.

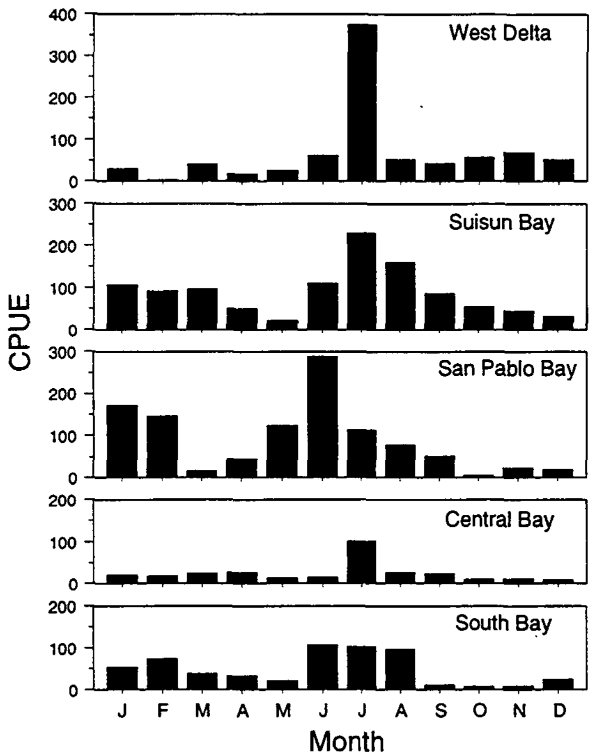

Figure 9 Monthly distribution (CPUE) of adult *C. franciscorum* in 1988

Salinity and temperature at point of capture varied with size and sex. The smallest juvenile *C. franciscorum* (11 to 15 mm) were collected at a mean salinity of 13‰ (Figure 11A). The mean salinity decreased slightly with size to 10‰ for shrimp 21 to 25 mm. The mean salinity increased steadily with size for female and male *C. franciscorum* >25 mm (Figures 11A and 11B). Females were collected at a maximum mean salinity of about 24‰ (76 to 80 mm) and males at a maximum mean salinity of about 23‰ (56 to 60 mm). The decrease in salinity for males in the 61 to 65 mm size group may be an aberration, as shrimp from only 3 tows ($n = 525$) in Carquinez Strait dominated this group. Males were consistently collected at a higher mean salinity than females of the same size up to 51–55 mm. For some size groups, this difference was >5‰. But at the approximate size of maturity, which is the 36 to 40 mm size group for males and the 46 to 50 mm size group for females, both sexes were collected at a similar mean salinity of about 15‰.

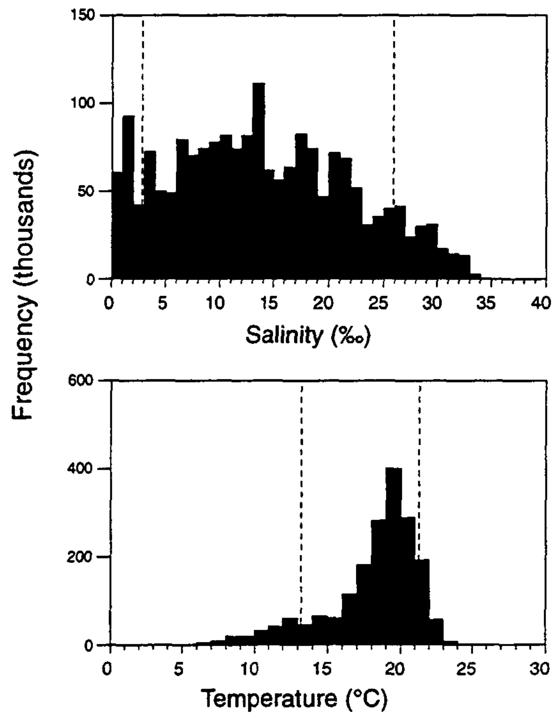

Figure 10 Salinity (‰) and temperature (°C) distributions of all sizes of *C. franciscorum* collected with the otter trawl (1980 to 1996). Dashed vertical lines are the 10th and 90th percentiles.

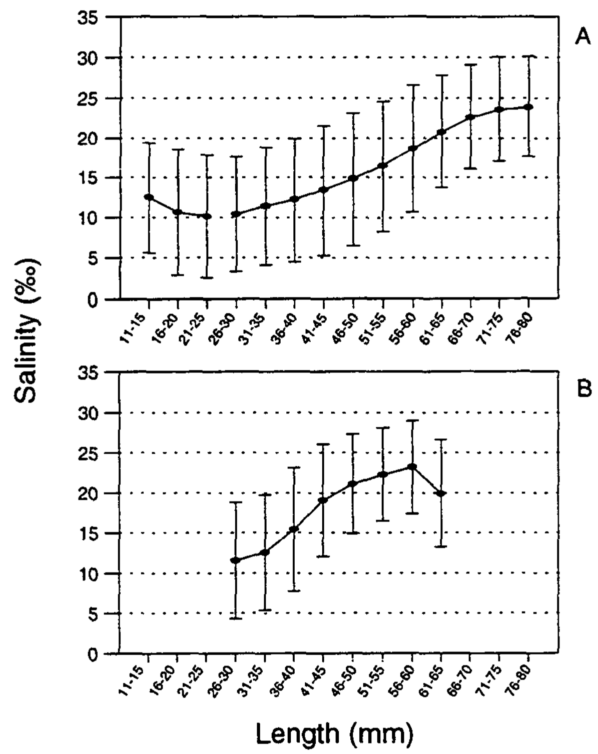

Figure 11 Mean salinity (±1 standard deviation) of *C. franciscorum* by size class collected with the otter trawl: (A) juveniles (11 to 25 mm) and females and (B) males. Size classes are every 5 mm, from 11 to 80 mm.

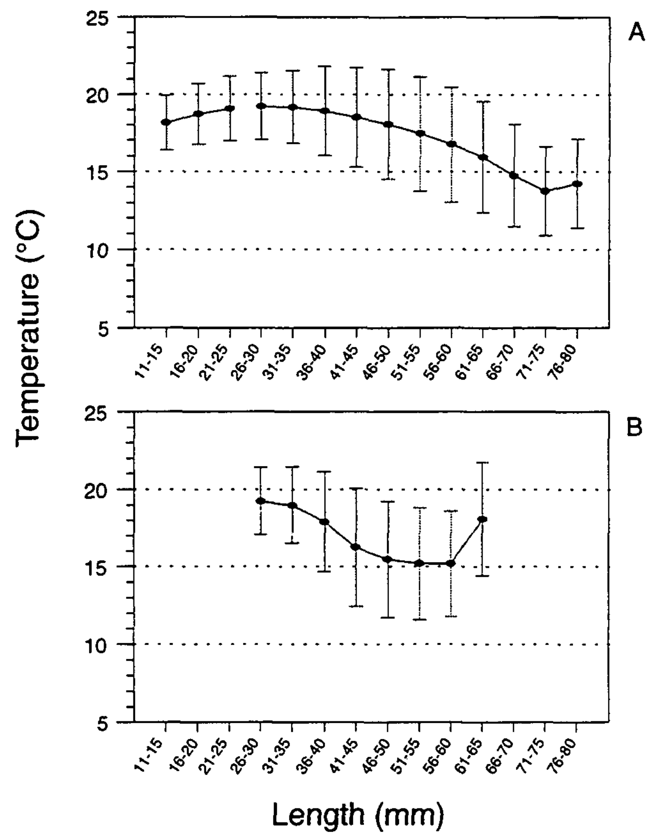

Figure 12 Mean temperature (±1 standard deviation) of *C. franciscorum* by size class collected with the otter trawl: (A) juveniles (11 to 25 mm) and females and (B) males. Size classes are every 5 mm, from 11 to 80 mm.

The smallest juvenile *C. franciscorum* (11 to 15 mm) were collected at a mean temperature of about 23 °C (see Figure 12A). The mean temperature increased slightly with size to about 19 °C for shrimp in the 21 to 25 and 26 to 30 mm size groups and then decreased with size for both sexes (Figures 12A and 12B). For any given size group, females were collected at a higher temperature than males (note the exception for the 61 to 65 mm males discussed in the previous paragraph). For some size groups, females were collected at a mean temperature which was 3 °C warmer than for the males, but this difference decreased with size. At the approximate sizes of maturity, males and females were collected at a similar mean temperature of about 18 °C.

Discussion

Crangon franciscorum is an estuarine species that dominated our shrimp catches in most years. The general life cycle of *C. franciscorum* as reported by other researchers is supported by this study's data. Peak abundance of juveniles occurred between May and September, when temperatures were typically warmest in the mesohaline nursery areas. Depending on the magnitude of freshwater outflow and the resulting salinities, the center of distribution of juvenile *C. franciscorum* ranged from San Pablo Bay to the west delta. Juveniles from the spring and early summer cohorts grew rapidly and apparently reached maturity by fall of the same year, and by November or December adult shrimp dominated our catches. As *C. franciscorum* matured, they moved downstream to cooler, polyhaline areas to reproduce. The center of distribution of adults, especially ovigerous females, is probably outside of the estuary in years with high freshwater outflow, as proposed by Hatfield (1985).

The highest annual juvenile abundance indices were in years with relatively high freshwater outflow in winter and spring whereas the lowest indices were in low outflow years. There is a strong positive relationship between the annual abundance of juvenile *C. franciscorum* and freshwater outflow which has been discussed in detail in previous reports (CDFG 1987, 1992). Annual abundance was strongly related to distribution, as juvenile *C. franciscorum* were concentrated in San Pablo or Suisun bays in high abundance years and concentrated in Suisun Bay or the west delta area, but never in San Pablo Bay, in low abundance years.

Although male *C. franciscorum* were consistently collected from cooler, more saline waters than females of the same size, at the onset of maturity, both sexes were collected at almost identical mean salinities. The salinity and temperature data indicate that, except for the sizes associated with the onset of maturity, males were generally distributed downstream of females. Analyses have confirmed that juvenile males are distributed downstream of juvenile females (CDFG unpublished data). Males may be located downstream from females so maturing females will pass by them during their downstream migration. Males of some species of caridean shrimp move to deeper water after mating, and females follow them after the larvae hatch (Allen 1966).

Crangon nigricauda

Crangon nigricauda, the blacktail bay shrimp, ranges from Prince William Sound, Alaska (Squires and Figueira 1974), to Baja California (Rathbun 1904) and is found in estuaries and the nearshore ocean area from the intertidal to 57 m (Jensen 1995). *Crangon nigricauda* is less tolerant of low salinities than *C. franciscorum* (Israel 1936, Ganssle 1966, Siegfried 1980) and is not common upstream of western Suisun Bay even during low outflow years (Israel 1936, CDFG 1987).

Crangon nigricauda is reported to have a single reproductive season from April through September in the San Francisco Estuary, although ovigerous females were collected all year (Israel 1936). Some females produce 2 broods during the reproductive season. In Yaquina Bay, Oregon, reproduction extends from December through mid-August but is bimodal, with peaks from December through March and May through August (Krygier and Horton 1975). Hatching time was estimated to be 10 to 14 weeks in winter and 8 to 10 weeks in summer. Most juveniles hatched in winter settle in June, while those hatched in summer settle in December. In the San Francisco Estuary, juveniles were most common in shallow water (<6 m) but were collected from deeper areas than juvenile *C. franciscorum* (Israel 1936). *Crangon nigricauda* are limited to low temperature, polyhaline waters in Yaquina Bay, with juveniles collected from warmer, lower salinity waters than adults. Most ovigerous *C. nigricauda* were collected at salinities >33‰ and temperatures ranging from 8 to 11 °C (Krygier and Horton 1975).

Female *C. nigricauda* were estimated to mature at 37 mm in the San Francisco Estuary (Israel 1936). In Yaquina Bay, females mature at 40 mm and males at 28 mm (Krygier and Horton 1975). Maximum reported size from the estuary is 60 mm for females and 45 mm for males (Israel 1936). Although Israel (1936) did not report a life span for *C. nigricauda*, he did report that it could reach its maximum size in 1 year. In Yaquina Bay, females reportedly live to 1.5 years and males to 1 year. Both sexes mature at 1 year and males probably spawn once and die (Krygier and Horton 1975). If *C. nigricauda* is a protandrous hermaphrodite as reported for *C. franciscorum*, males would transition to females at approximately 1 year and would live to at least 1.5 years as females. As for *C. franciscorum*, this life history strategy would account for the apparent shorter life span and smaller size of male *C. nigricauda* reported by other researchers.

Methods

Crangon nigricauda juveniles were separated from adults based on a size of maturity of 28 mm for males (Krygier and Horton 1975, CDFG unpublished data) and 33 mm for females (only 1% of the ovigerous females we collected were less than 33 mm). The juvenile and adult categories were used for abundance and distribution analyses and 5 mm size groups by sex were used for the salinity and temperature analyses. The annual index periods selected were May through September for juveniles and February through September for adults. Although the February through September period omitted months when the abundance of adult *C. nigricauda* was often high, it was necessary so the 1989 through 1994 data could be included in the annual analyses. For analysis of seasonal distribution patterns, 1983 and 1988 were selected as representative high and low outflow years for both juvenile and adult *C. nigricauda*. Length frequency data from 1988 were used to demonstrate the monthly length frequency distributions.

Results

Length Frequency

The maximum sizes of *C. nigricauda* collected by our study were 64 mm for females and 60 mm for males (only 4 males were >55 mm). Monthly length frequency histograms for 1988 give a general picture of the timing of cohorts and growth rates, but the number and timing of cohorts of *C. nigricauda* varied so much that no single year represented a norm. In January 1988, there were 2 male cohorts and possibly several female cohorts of *C. nigricauda* in the estuary (Figure 13). The smaller male cohort was primarily juveniles and the larger cohort adults. By March, there was little evidence of multiple cohorts and the modal length for both sexes was greater than the size of maturity. In April, a cohort of juvenile *C. nigricauda* appeared, but the adult mode remained distinct. In May, the larger *C. nigricauda* all but disappeared, although some adult females from the previous year continued to be collected through summer. During the rest of the year, several cohorts of juvenile *C. nigricauda* entered the estuary—a relatively large cohort in June and smaller cohorts from September through November. The shrimp from each cohort eventually overlapped in size as they reached maturity and the occurrence of several cohorts from spring through fall broadened the length frequency histograms. There appeared to be 2 distinct cohorts from September through November, and by November the modal length of the larger cohort was at or larger than the size of maturity of both sexes.

Abundance

Crangon nigricauda was the second most common species of caridean shrimp collected during the study period and was the most common species from 1990 to 1992 (see Table 1). The annual abundance of juvenile *C. nigricauda* was relatively low from 1980 to 1987, increased from 1988 to 1990, and remained relatively high from 1991 to 1996 (Figure 14A, Table 4). The highest indices were in 1990 and 1996 and the lowest indices were in 1981, 1982, 1984, and 1985. The juvenile and adult annual abundance trends were similar, although the highest adult index was in 1991 (Figure 14B, Table 5), the year after the highest juvenile index. The lowest adult *C. nigricauda* indices were from 1981 through 1985.

Seasonal abundance of juvenile *C. nigricauda* was bimodal, with the larger peak from May through August, and a smaller peak from December through February (Figure 15, see Table 4). The winter cohort was relatively large in some years (for example, 1986 to 1987 and 1987 to 1988). The monthly abundance of adult *C. nigricauda* was also bimodal (see Figure 15, see Table 5), with the major peak from November through February and a secondary peak from May through August. In years with 12 months of data, the winter peak was always larger than the following summer peak except for winter 1985–1986.

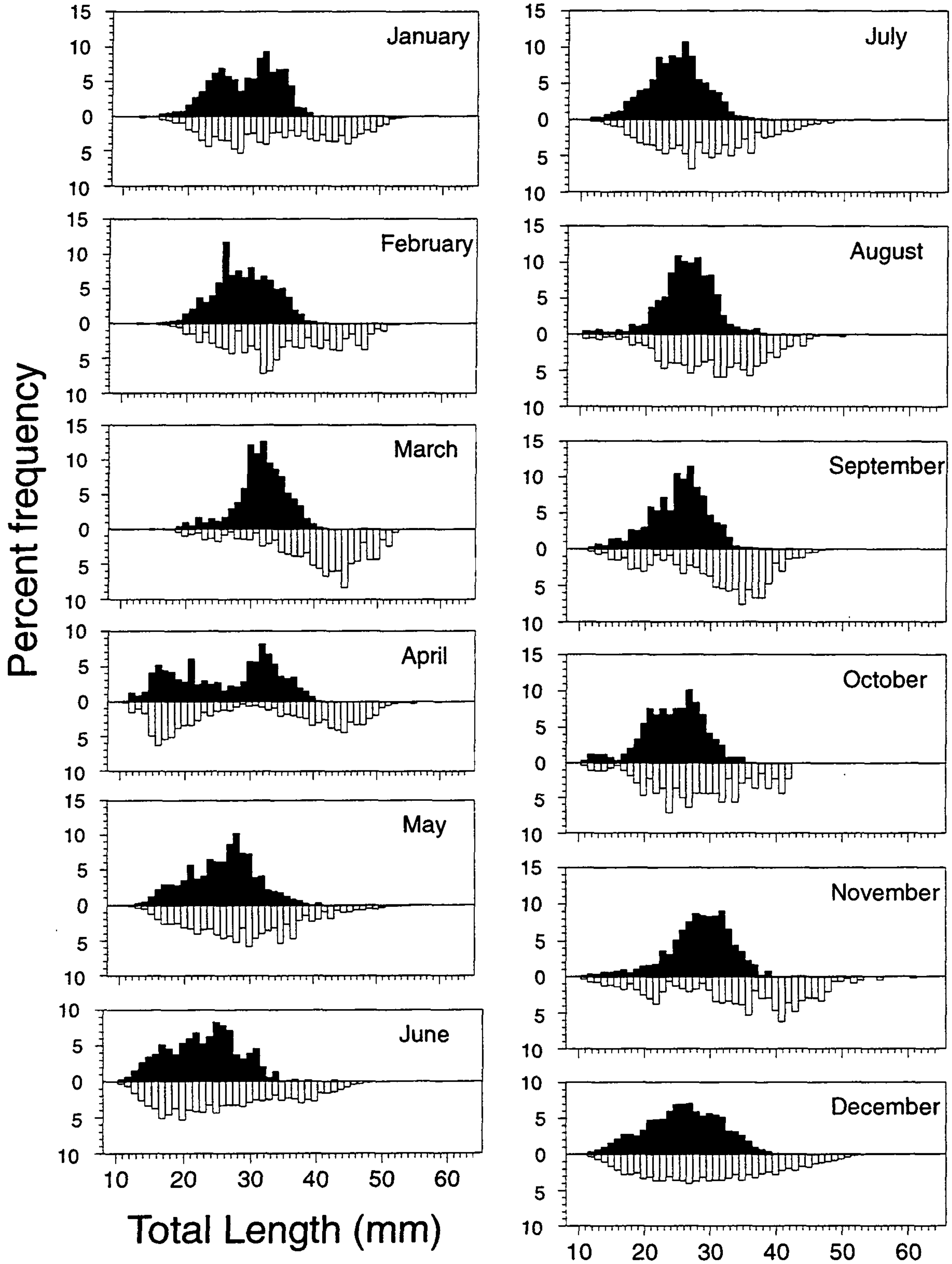

Figure 13 Monthly percent length frequencies of male (closed bars) and female (open bars) ***C. nigricauda*** **collected with the otter trawl in 1988.** Size classes are every 1 mm, from 11 to 65 mm.

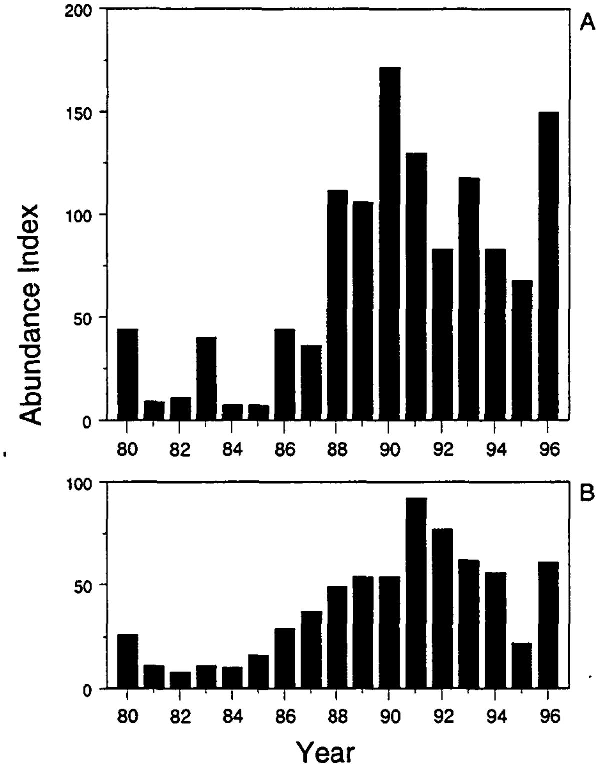

Figure 14 Annual abundance indices of *C. nigricauda* collected with the otter trawl: (A) juveniles (1980 to 1996), the index period is May to September and the indices are divided by 1000; (B) adults (1980 to 1996), the index period is February to September and the indices are divided by 1000

Table 4 Monthly and annual abundance indices of juvenile *C. nigricauda* collected with the otter trawl from 1980 to 1996. The index period is May to September and the indices are divided by 1,000.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*May–Sep*
1980		24	18	9	3	137	33	28	18	2	7	8	44
1981	14	19	15	17	27	1	5	3	8	10	0	12	9
1982	17	3	2	5	29	14	1	1	8	6	9	5	11
1983	25	16	9	22	2	28	16	153	1	8	9	12	40
1984	8	2	3	6	14	7	7	6	1	2	2	2	7
1985	3	4	0	0	5	14	11	1	4	4	2	3	7
1986	2	1	12	2	5	107	29	47	32	16	20	44	44
1987	36	38	14	6	1	18	38	50	73	57	57	63	36
1988	86	22	2	29	176	233	103	26	22	3	5	5	112
1989	18	22	45	54	169	102	57	95					106
1990		37	109	27	119	290	211	152	90	31			172
1991		39	94	87	61	222	111	113	142	59			130
1992		54	34	9	69	197	71	41	37	43			83
1993		23	12	18	51	215	277	35	12	3			118
1994		6	5	15	44	190	65	77	37	7			83
1995	12	14	72	9	35	145	50		42	9	4	18	68
1996	59	29	51	83	214	154	190	157	34	15	10	14	150
1981–1988, 1996	28	15	12	19	53	64	45	49	20	13	13	18	

Table 5 Monthly and annual abundance indices of adult *C. nigricauda* collected with the otter trawl from 1980 to 1996. The index period is February to September and the indices are divided by 1,000.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Sep*
1980		59	29	9	11	29	26	31	12	2	12	8	26
1981	41	21	15	25	7	1	10	5	3	8	1	41	11
1982	34	6	7	4	16	19	1	4	9	9	3	9	8
1983	44	22	11	19	10	5	6	16	2	4	8	20	11
1984	14	3	9	6	19	21	12	9	1	3	5	7	10
1985	13	56	4	4	3	36	21	3	3	4	3	10	16
1986	20	29	29	11	6	20	47	67	25	15	18	62	29
1987	52	63	41	11	9	13	42	58	62	86	123	154	37
1988	147	35	23	51	122	78	43	18	19	2	8	12	49
1989	27	52	65	47	64	46	50	56					54
1990		65	123	36	66	54	43	26	20	18			54
1991		145	143	70	83	101	60	62	75	45			92
1992		226	76	32	100	87	36	18	43	39			77
1993		83	50	21	36	71	134	67	30	14			62
1994		27	18	24	37	79	66	123	78	19			56
1995	42	25	28	10	22	18	16		32	16	36	102	22
1996	78	26	60	62	103	65	63	43	67	18	46	66	61
1981–1988, 1996	49	29	22	22	33	29	27	25	21	16	24	43	

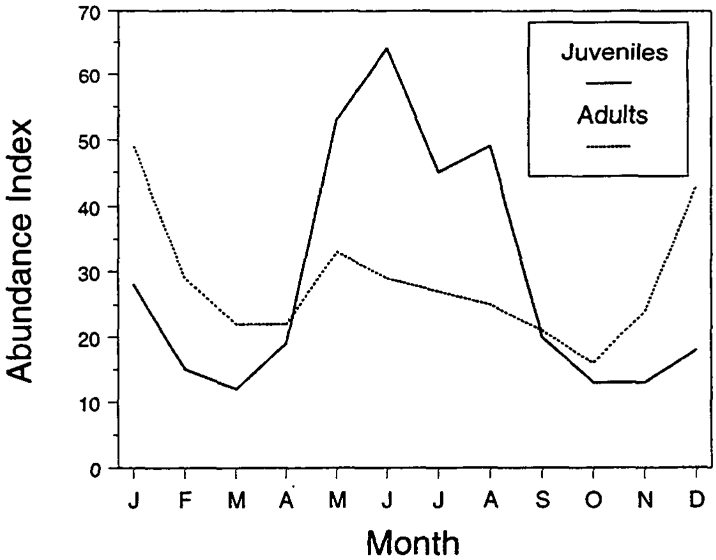

Figure 15 Monthly abundance indices of juvenile and adult *C. nigricauda* collected with the otter trawl from 1981 to 1988 and 1996. The indices are divided by 1,000.

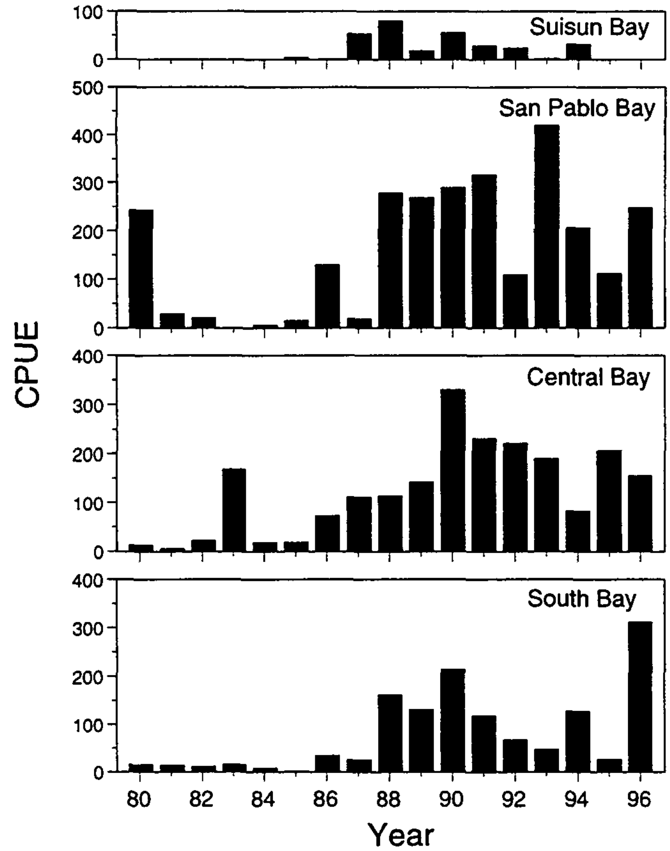

Figure 16 Annual distribution (CPUE) of juvenile *C. nigricauda* for May through September from 1980 to 1996

Distribution

Juvenile and adult *C. nigricauda* were collected from South to Suisun bays, although the extension to Suisun Bay primarily occurred during the drought years 1987–1992 (Figures 16 and 17). On an annual basis (May to September), the center of distribution of juveniles was usually in San Pablo Bay in low outflow years and Central Bay in high outflow years (see Figure 16). Major exceptions include 1980 and 1986, high outflow years when CPUE was highest in San Pablo Bay, and 1987, 1990, and 1992, low outflow years when CPUE was highest in Central Bay. Juvenile CPUE was highest in South Bay in 1996, a high outflow year, and higher in South Bay than Central Bay in 1988 and 1994, both low outflow years.

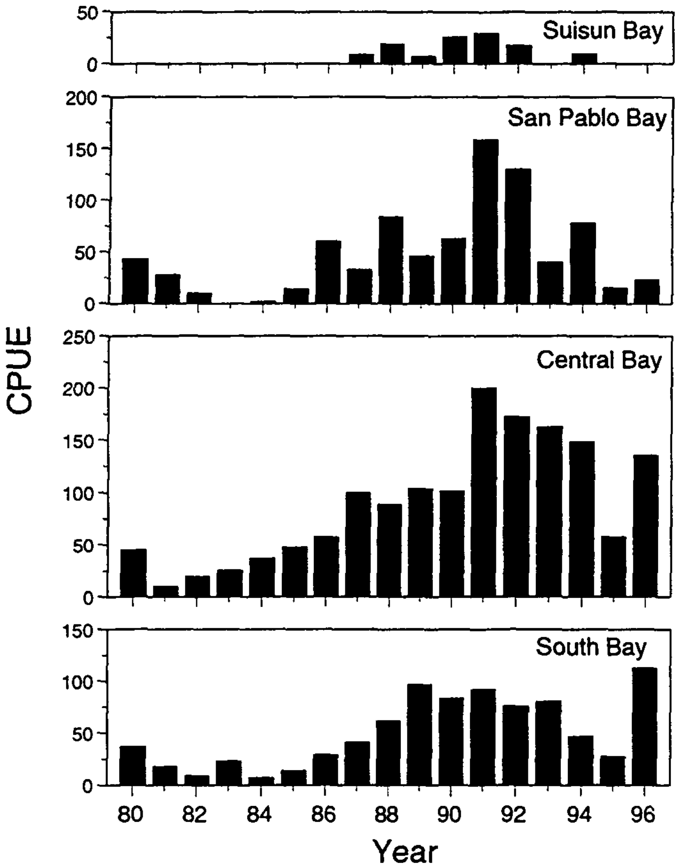

Figure 17 Annual distribution (CPUE) of adult *C. nigricauda* for February through September from 1980 to 1996

Annually, the center of distribution of adult *C. nigricauda* was in Central Bay all years except 1981, when CPUE was highest in San Pablo Bay (see Figure 17). Although South Bay never had the highest annual CPUE of adult *C. nigricauda*, it often had the 2nd highest CPUE of all embayments. Surprisingly, South Bay CPUE was relatively high in both high outflow (1983 and 1996) and low outflow (1981 and 1989) years.

Juvenile *C. nigricauda* moved seasonally between South, Central, and San Pablo bays, but the extent and timing of this movement varied with outflow. In 1983, a "wet" year, CPUE was highest in South Bay from January though June (Figure 18). The center of distribution shifted to Central Bay in July and remained there through December. Some movement to San Pablo Bay occurred in November and December. In lower outflow years, the center of distribution of juveniles was in San Pablo Bay from January to June, although as abundance increased in May, CPUE was also relatively high in South Bay (Figure 19). From July through September, CPUE decreased in South, San Pablo and Suisun bays and distribution was centered in Central Bay. From October to December, CPUE decreased in Central Bay and the center of distribution shifted to either South or San Pablo bays.

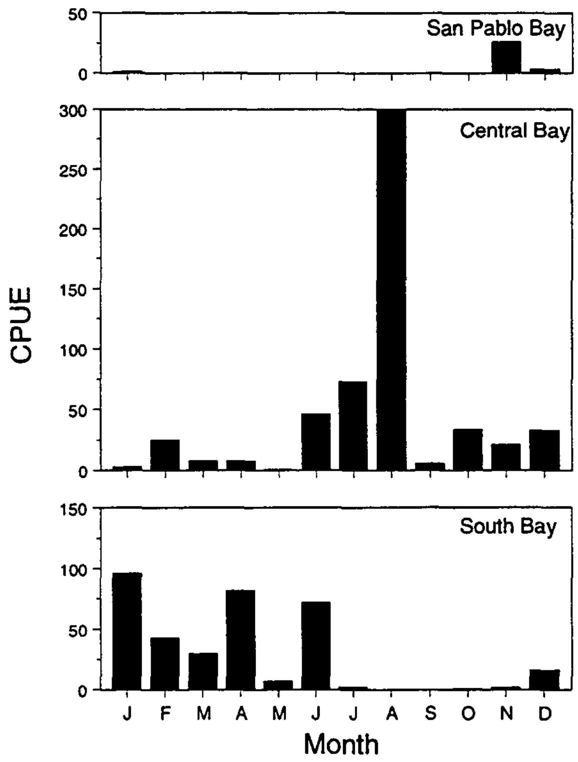

Figure 18 Monthly distribution (CPUE) of juvenile *C. nigricauda* in 1983

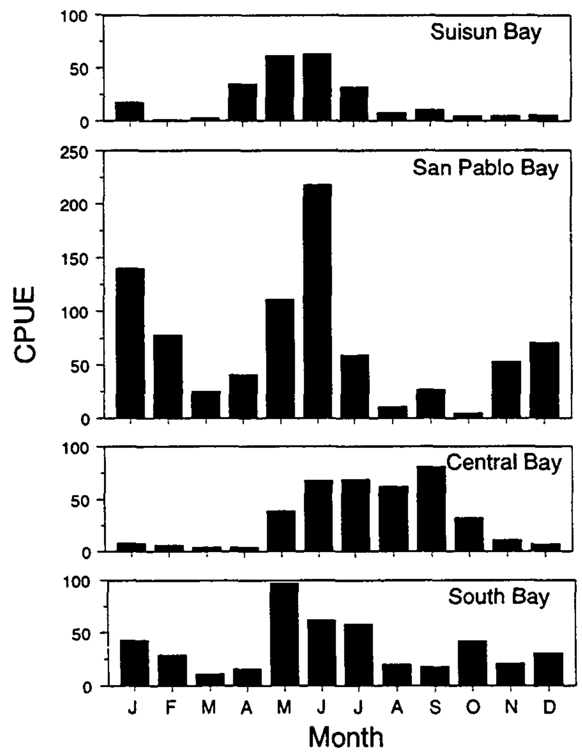

Figure 19 Monthly distribution (CPUE) of juvenile *C. nigricauda* in 1981, 1985, 1987, and 1988

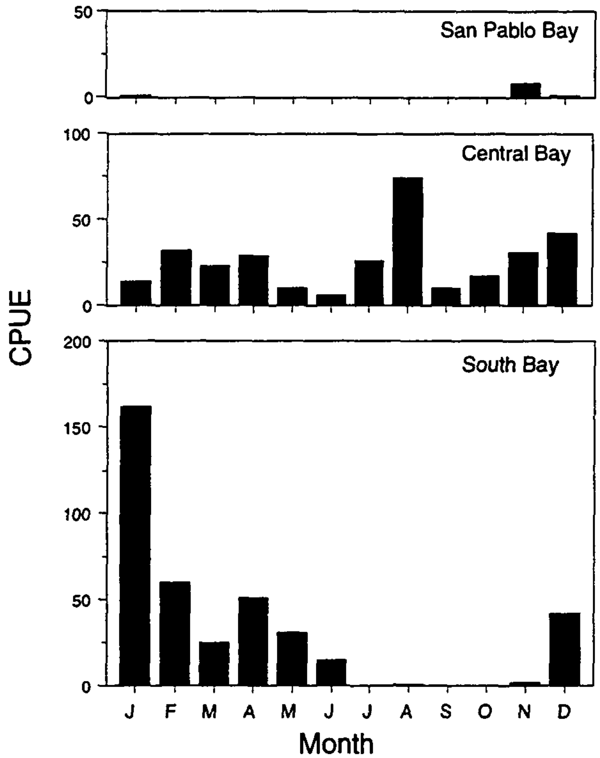

Figure 20 Monthly distribution (CPUE) of adult *C. nigricauda* in 1983

In 1983, adult *C. nigricauda* were concentrated in South Bay from January to June (Figure 20). The center of distribution shifted to Central Bay in July, and remained there until December, when CPUE again increased in South Bay. Some limited movement to San Pablo Bay occurred in November and December. In low outflow years, adult *C. nigricauda* CPUE was highest in South Bay in January (Figure 21); CPUE was also high in San Pablo Bay in January. From February through June, there was a somewhat erratic trend of CPUE decreasing in South and San Pablo bays and the center of distribution shifting to Central Bay. But from July to October, adult *C. nigricauda* were definitely concentrated in Central Bay. In November and December, CPUE increased in South and San Pablo bays and decreased in Central Bay. The December distribution was very similar to the January distribution.

Salinity and Temperature

Crangon nigricauda was collected over a wide range of salinities and temperatures; 80% were found from 18.0‰ to 31.7‰ and 10.7 and 19.3 °C (10th and 90th percentiles, respectively, Figure 22). For all sizes, the mean salinity was 25.9‰ and the mean temperature was 15.5 °C.

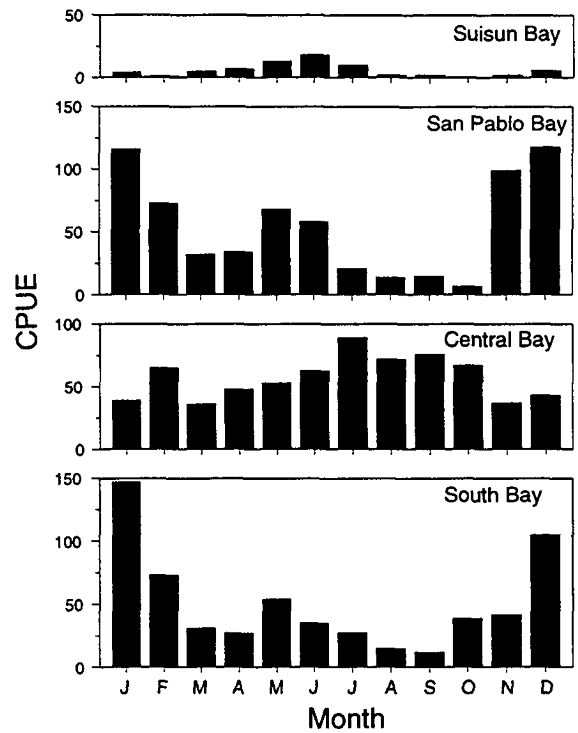

Figure 21 Monthly distribution (CPUE) of adult *C. nigricauda* in 1981, 1985, 1987, and 1988

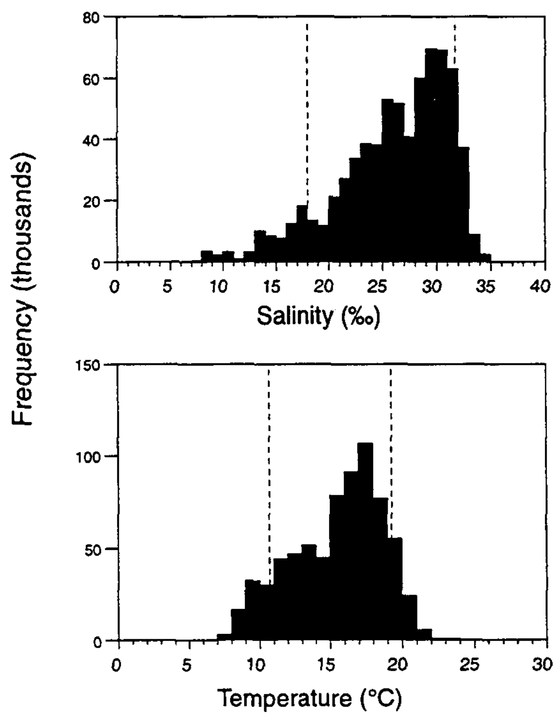

Figure 22 Salinity (‰) and temperature (°C) distributions of all sizes of *C. nigricauda* collected with the otter trawl (1980 to 1996). Dashed vertical lines are the 10th and 90th percentiles.

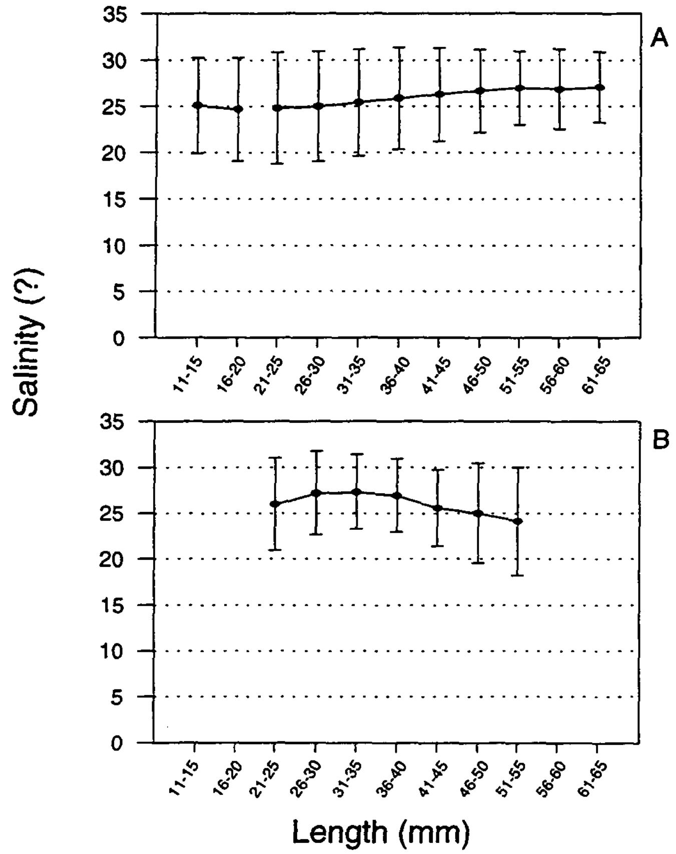

Figure 23 Mean salinity (±1 standard deviation) of *C. nigricauda* by size class collected with the otter trawl: (A) juveniles (11 to 20 mm) and females and (B) males. Size classes are every 5 mm, from 11 to 65 mm.

Unlike *C. franciscorum*, the mean salinity did not change appreciably with size (Figure 23). The smallest juvenile *C. nigricauda* (11 to 15 mm) were collected at a mean salinity of about 25‰ (see Figure 23A). The mean salinity decreased slightly for juveniles in the 16 to 20 mm size group and then slowly increased with size for females (see Figure 23A); the largest female size classes were collected at the highest mean salinity (about 27‰). The mean salinity for males was about 27‰ for the 26 to 35 mm size group and decreased to about 25‰ for the 51 to 55 mm size group (see Figure 23B). Males were collected at a higher mean salinity than same-sized females until 41 to 45 mm. The smallest juveniles (11 to 15 mm) were collected at a mean temperature of about 17 °C (Figure 24B). The mean temperature slowly decreased with size for females 21 to 40 mm and decreased more rapidly for females >40 mm. The largest females were collected at a mean temperature of about 12 °C. Male *C. nigricauda* were also collected at decreasing temperature with size (Figure 24A), although the decline was somewhat erratic for males >45 mm. From 26 to 45 mm, males were collected at a lower mean temperature than same sized females. But at the size classes which encompass the onset of maturity (26 to 30 mm for males, 31 to 35 mm for females), both sexes were collected at a mean temperature of about 16 °C.

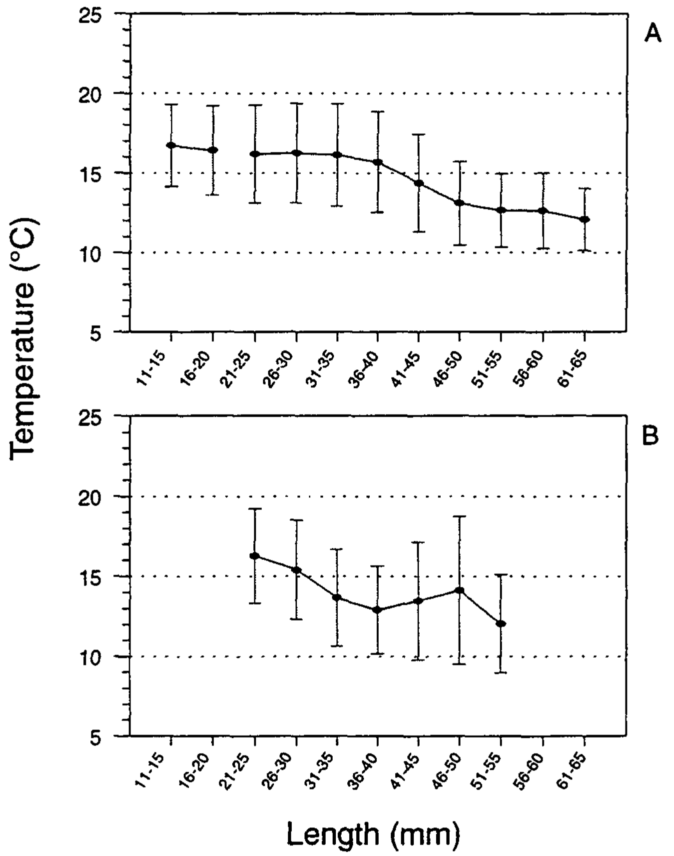

Figure 24 Mean temperature (±1 standard deviation) of *C. nigricauda* by size class collected with the otter trawl: (A) juveniles (11 to 20 mm) and females; (B) males. Size classes are every 5 mm, from 11 to 65 mm.

Discussion

Crangon nigricauda is an important component of the San Francisco Estuary's caridean shrimp community; it was the 2nd most common species collected during the study period and in some years the most common. It was widely distributed in the cooler, polyhaline areas of the estuary. Although not as euryhaline as *C. franciscorum*, it is well adapted to conditions downstream of Carquinez Strait. During extended periods of low outflow, *C. nigricauda* possibly completes its entire life cycle in the estuary.

Crangon nigricauda annual abundance increased steadily from 1986 through 1991 and remained well above the pre–1987 levels through 1996. This increase in abundance was partly due to large contributions by fall and winter cohorts during 1986 to 1987, 1987 to 1988, and possibly subsequent years. As data was not collected from winter 1989–1990 to winter 1994–1995, it is unknown if abundance was relatively high in these winters and how the annual abundance indices would be affected if 12 months of data were available. Despite the data gaps from 1989 through 1994, *C. nigricauda* abundance was definitely high these years relative to previous years.

It is possible that *C. nigricauda* increased its use of the estuary during the 1987–1992 drought because of the increased availability of polyhaline (18‰ to 30‰) habitat, especially in winter when temperatures were cooler. But this hypothesis does not account for the continued high abundance after the drought—the 2nd highest index of juvenile *C. nigricauda* was in 1996, which was classified as a "wet" year.

Abundance of juvenile *C. nigricauda* usually peaked from May through August, but was bimodal in some years, with a 2nd fall-winter peak. Compared to *C. franciscorum*, fall cohorts were relatively large in some years. Adult *C. nigricauda* were most abundant in winter with a 2nd smaller peak in summer of most years. As *C. nigricauda* are reported to mature within 1 year, most of the adult females and males present in the winter are assumed to have hatched in spring of the same year. Adult *C. nigricauda* collected in summer were probably a mixture of older females hatched the previous spring (that is, 1.5 years old) and younger shrimp from the fall-winter cohort. The length frequency data from 1988 somewhat confirms this age structure, although the appearance of multiple cohorts through the spring and summer served to broaden the modes in several months. Israel (1936) noted that the breeding population of *C. nigricauda* present in the estuary from April through September were shrimp hatched the previous year. He reported a modal length of 14 mm in December 1933; by April 1934, the male mode was 31 mm and the female mode 41 mm.

Juvenile *C. nigricauda* were collected further upstream and at lower salinities and higher temperatures than adults, but the mean salinity did not appreciably increase with size as for *C. franciscorum*. Mean temperature did decrease with size for both sexes, which may reflect a movement to deeper, cooler water with age and decreasing temperatures concurrent with maturation through winter.

Crangon nigricauda ranged from South to San Pablo bays in all years except 1983, when low salinity limited them to South and Central bays. Juveniles and adults expanded their distributions to Suisun Bay in years with low freshwater outflow, particularly from 1987 through 1992. The use of Central Bay was also influenced by decreased salinities during periods of high outflow. During the winter and spring of 1983, juvenile and adult *C. nigricauda* were concentrated in South Bay and as outflow decreased and salinities increased, they moved to Central Bay. Use of South, San Pablo, and Suisun bays appears to be limited by temperature in summer and fall. From July through September, mean bottom temperatures in these embayments are usually >19 °C (see Salinity and Temperature chapter, Figures 7, 8, and 10), which is warmer than most *C. nigricauda* were collected at. This response to temperature and salinity is similar to what was reported in Yaquina Bay (Krygier and Horton 1975). Abundance of *C. nigricauda* decreased at the upstream sites in Yaquina Bay from June through October as temperatures increased and increased again in the fall as temperatures decreased. Krygier and Horton hypothesized that temperature in the summer and salinity in the winter controlled the distribution of *C. nigricauda* in Yaquina Bay.

Crangon nigromaculata

Crangon nigromaculata, the blackspotted bay shrimp, ranges from the Farallon Islands, California to Turtle Bay, Baja California (Rathbun 1904) and is more common in the nearshore ocean area than in estuaries. It is found on sand bottoms at depths ranging from 5 to 174 m and reaches a maximum size of approximately 70 mm (Jensen 1995). During an early survey of San Francisco Bay and the Gulf of the Farallones, *C. nigromaculata* was collected from South Bay in the vicinity of Hunter's Point to Central Bay and in the Gulf of the Farallones to 55 m; all specimens were collected at temperatures from 8.8 to 17.2 °C and salinities from 27.8‰ to 34.1‰ (Schmitt 1921). Based on nearshore ocean sampling by the City of San Francisco, *C. nigromaculata* is the most abundant species of *Crangon* in the Gulf of the Farallones (Michael Kellog, personal communication, see "Notes"). Only sparse information exists on the life history of *C. nigromaculata* in the estuary and the nearshore ocean.

Methods

Crangon nigromaculata juveniles were separated from adults based on a size of maturity of 28 mm for males (CDFG, unpublished data) and 42 mm for females (approximately 1% of the ovigerous *C. nigromaculata* we collected were <42 mm). The juvenile and adult categories were used for abundance and distribution analyses and 5 mm groups by sex were used for salinity and temperature analyses. The annual index periods selected were April through October for juveniles and February through October for adults. The February through October period omitted months when the abundance of adult *C. nigromaculata* was often high, but was necessary for the inclusion of the 1989 through 1994 data in the annual analyses. For seasonal distribution analyses, 1996 was selected as a representative year for both juvenile and adult *C. nigromaculata,* and length frequency data from 1988 were used to demonstrate the typical monthly length frequency patterns.

Results

Length Frequency

We collected male *C. nigromaculata* to 59 mm and females to 72 mm. In January 1988, a large number of juvenile shrimp remained from a cohort which first appeared in late 1987 (Figure 25). Catches decreased significantly in February and March but the same cohort was collected in higher numbers in April. In May, a new cohort of juvenile shrimp appeared while a few shrimp from the older cohort were still present and had reached maturity. From June through August few *C. nigromaculata* of any cohort were collected. Another cohort of juvenile shrimp appeared in September and was again followed by very low catches. In November and December juvenile and adult cohorts were again distinguishable.

Abundance

Crangon nigromaculata was the 3rd most common species of caridean shrimp collected in the San Francisco Estuary over the study period (see Table 1). In 1992, it was the 2nd most common species, but from 1980 to 1982 and 1984 to 1986 is was either the 4th or 5th most common species. The annual abundance trends of juvenile and adult *C. nigromaculata* were very similar. Abundance of juvenile *C. nigromaculata* was relatively low from 1980 through 1989 and consistently increased from 1990 through 1993 (Figure 26A, Table 6). The highest annual index was in 1993 and the lowest indices were from 1980 to 1982 and in 1985. The highest indices for adult *C. nigromaculata* were from 1991 through 1994 and the lowest indices from 1980 to 1986 (Figure 26B, Table 7). Juveniles were more abundant than adults in every year except 1985 and over all the years, juveniles comprised 69% of the total *C. nigromaculata* index. The annual indices for adult *C. nigromaculata* were biased low in most years because the adults were usually most abundant in late fall and winter and the annual indices excluded November through January.

The seasonal abundance of juvenile *C. nigromaculata* was unimodal, with a peak in August and high abundance from May through September (Figure 27, see Table 6). But when the individual years are examined, the period of peak abundance ranged from late spring to winter (see Table 6). Several years had multiple abundance peaks; for example, in 1988 juvenile abundance peaked in January, April to May, September, and November to December. The length frequency data (above) indicates that each peak was a distinct cohort. Adult *C. nigromaculata* were most abundant from November through January, with a secondary peak in summer of some years (see Figure 27, see Table 7).

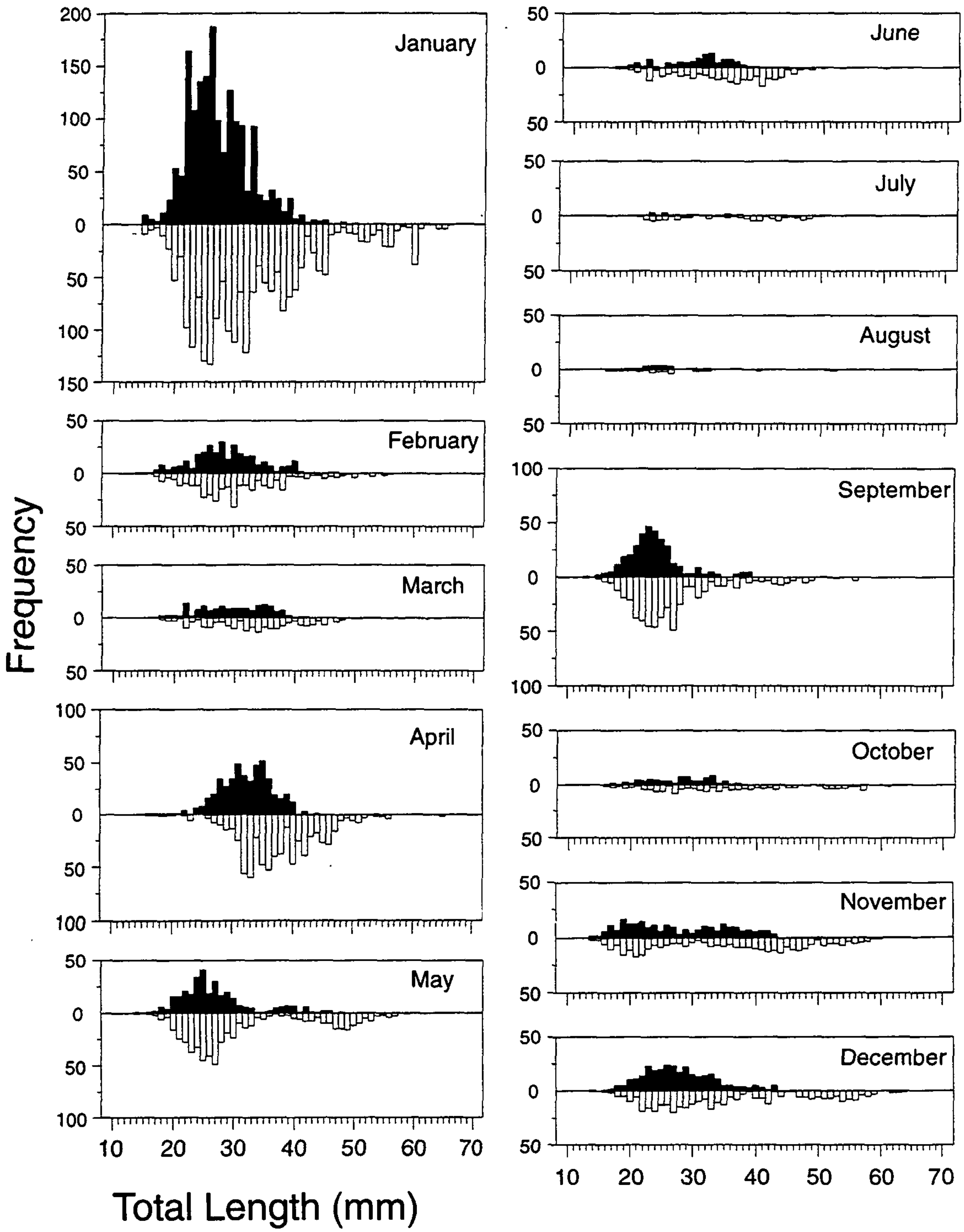

Figure 25 Monthly length frequencies of male (filled bars) and female (open bars) *C. nigromaculata* **collected with the otter trawl in 1988.** Size classes are every 1 mm, from 11 to 70 mm.

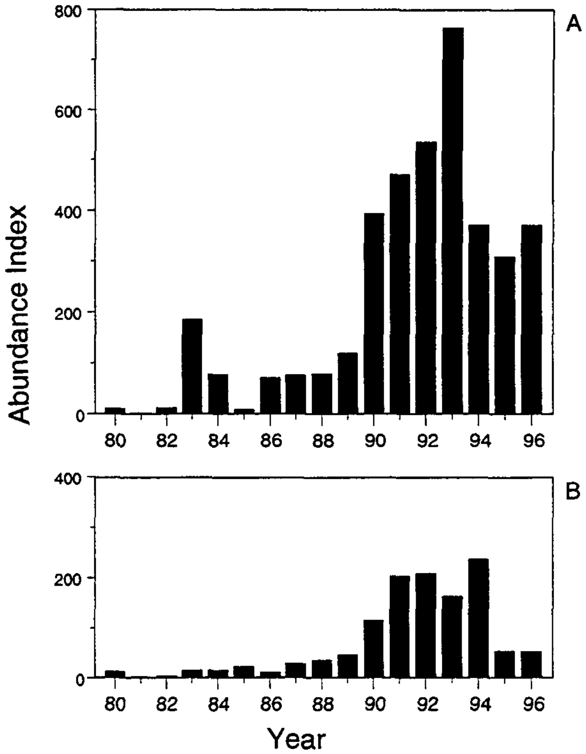

Figure 26 Annual abundance indices of *C. nigromaculata* collected with the otter trawl: (A) juveniles (1980 to 1996), the index period is April to October and the indices are divided by 100; (B) adults (1980 to 1996), the index period is February to October and the indices are divided by 100

Table 6 Monthly and annual abundance indices of juvenile *C. nigromaculata* collected with the otter trawl from 1980 to 1996. The index period is April to October and the indices are divided by 100.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Apr–Oct*
1980		47	3	1	18	24	6	12	13	3	4	0	11
1981	7	2	1	0	0	0	8	2	0	6	0	16	2
1982	8	1	0	0	31	29	3	2	14	12	5	5	13
1983	4	1	0	0	0	0	102	1108	34	54	168	49	185
1984	32	8	6	4	191	335	7	9	1	0	1	8	78
1985	4	13	1	7	0	28	15	0	4	7	3	4	9
1986	23	3	0	1	8	19	60	265	125	28	6	30	72
1987	16	50	3	2	25	30	12	74	85	313	216	220	77
1988	189	51	30	125	119	53	9	12	205	34	85	85	79
1989	152	42	69	161	121	132	128	57					120
1990		103	130	93	240	249	158	425	826	770			394
1991		225	309	238	293	426	502	258	719	861			471
1992		147	198	37	408	1209	123	322	816	837			536
1993		152	95	282	1735	998	1497	495	50	295			765
1994		120	189	56	534	653	201	603	420	130			371
1995	164	168	198	45	291	1361	76		35	40	65	133	308
1996	168	38	57	81	272	222	708	734	410	170	285	463	371
1981–1988, 1996	35	10	9	13	72	90	129	303	84	40	67	82	

Table 7 Monthly and annual abundance indices of adult *C. nigromaculata* collected with the otter trawl from 1980 to 1996. The index period is February to October and the indices are divided by 100.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		47	6	0	10	32	8	4	5	7	2	0	13
1981	16	3	2	0	0	0	9	3	0	4	0	11	2
1982	11	1	0	0	2	18	1	2	9	8	1	4	4
1983	11	0	0	0	0	0	12	78	11	37	161	108	15
1984	20	8	6	3	22	85	6	8	0	0	1	17	15
1985	26	140	19	7	3	24	9	0	0	2	4	18	23
1986	87	10	0	0	2	9	11	25	16	25	39	176	11
1987	70	77	9	1	4	6	11	38	43	85	147	163	30
1988	114	33	28	130	55	28	7	2	20	22	58	50	36
1989	130	32	35	41	64	79	45	25					46
1990		88	60	28	95	113	26	21	128	482			116
1991		300	75	96	63	125	168	99	157	754			204
1992		256	214	74	141	266	17	17	515	383			209
1993		316	231	97	198	218	183	67	13	158			164
1994		328	283	138	210	213	124	404	324	110			237
1995	368	236	95	16	24	15	2		14	32	163	306	54
1996	195	30	12	11	38	59	45	67	125	96	464	457	53
1981–1988, 1996	52	27	6	3	9	28	13	26	23	24	96	113	

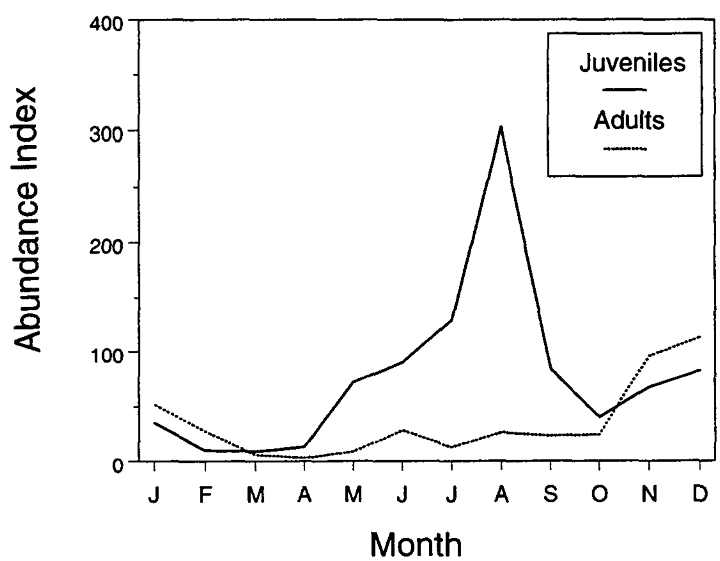

Figure 27 Monthly abundance indices of juvenile and adult *C. nigromaculata* collected with the otter trawl from 1981 to 1988 and 1996. The indices are divided by 100.

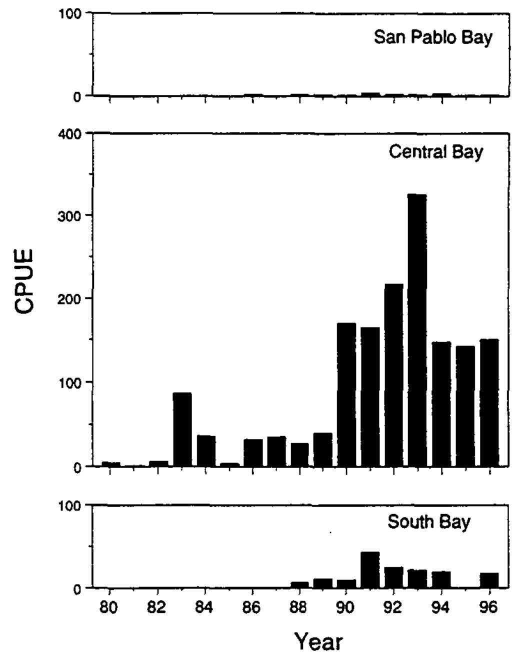

Figure 28 Annual distribution (CPUE) of juvenile *C. nigromaculata* for April to October from 1980 to 1996

Distribution

The center of distribution of *C. nigromaculata* was usually in Central Bay, and annual and seasonal changes in distribution were not as pronounced as for either *C. franciscorum* or *C. nigricauda*. Both juveniles and adults extended their distribution to South Bay and, to a lesser extent, San Pablo Bay, especially from 1988 through 1992 (Figures 28 and 29). In San Pablo Bay, *C. nigromaculata* was primarily restricted to the channel and the shoals of its southern part.

There were no strong seasonal trends in the distribution of either juvenile or adult *C. nigromaculata* (Figures 30 and 31), as their distribution was centered in Central Bay in all months. South Bay CPUEs were highest in winter and relatively low in summer. CPUEs increased slightly in San Pablo Bay in late fall and winter but were essentially 0 through the summer.

Salinity and Temperature

Most *C. nigromaculata* were collected from a relatively narrow range of salinities and temperatures—80% were from 25.9‰ to 31.9‰ and 10.9 to 17.8 °C (10th and 90th percentiles, respectively, Figure 32). The mean salinity for all sizes of *C. nigromaculata* was 29.4‰ and the mean temperature was 14.9 °C. There was essentially no change in mean salinity with size for juvenile (11 to 20 mm), female, or male *C. nigromaculata*, and both sexes were collected at almost identical mean salinities (Figure 33). Mean temperature was about 15 °C for the smallest juveniles, increased slightly with size and then decreased (Figure 34). The largest females (66 to 70 mm) and males (51 to 55 mm) were collected at a mean temperature of about 12 °C. Males >30 mm were collected at lower mean temperatures than same-sized females, but at the size classes which encompass the onset of maturity (26 to 30 mm for males, 41 to 45 mm for females), the mean temperatures were almost identical.

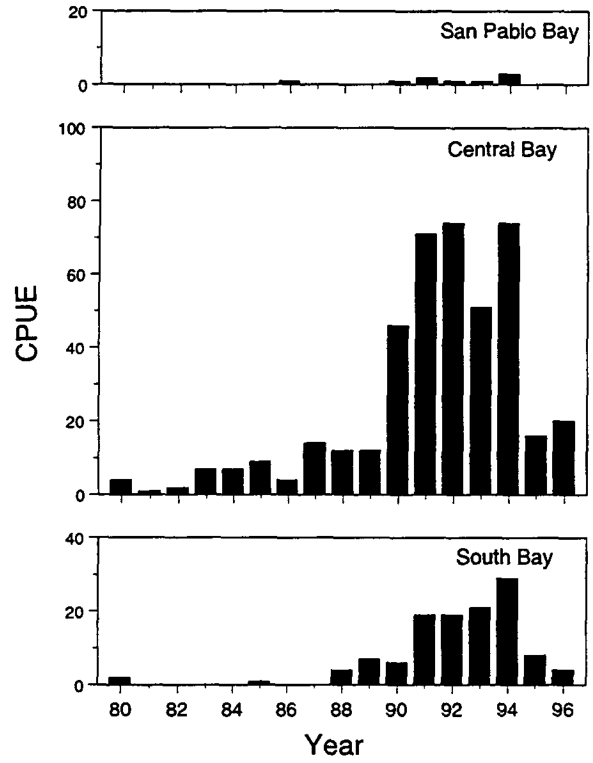

Figure 29 Annual distribution (CPUE) of adult *C. nigromaculata* for February to October from 1980 to 1996

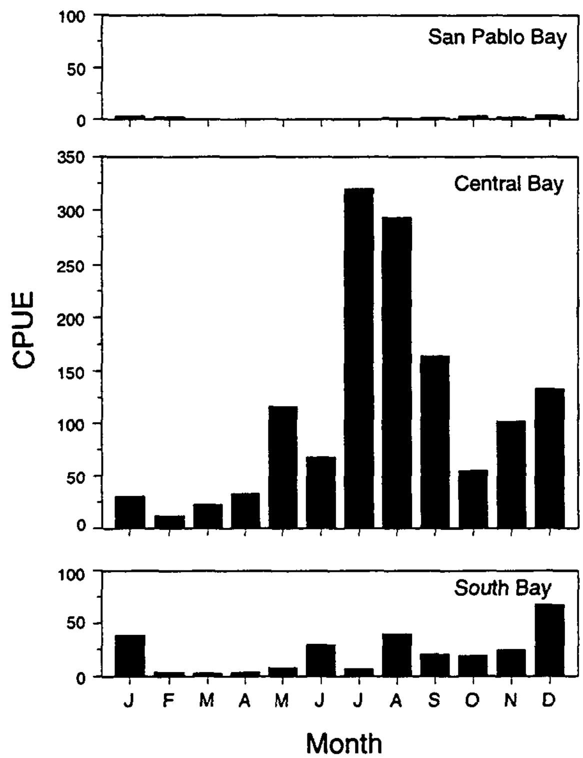

Figure 30 Monthly distribution (CPUE) of juvenile *C. nigromaculata* in 1996

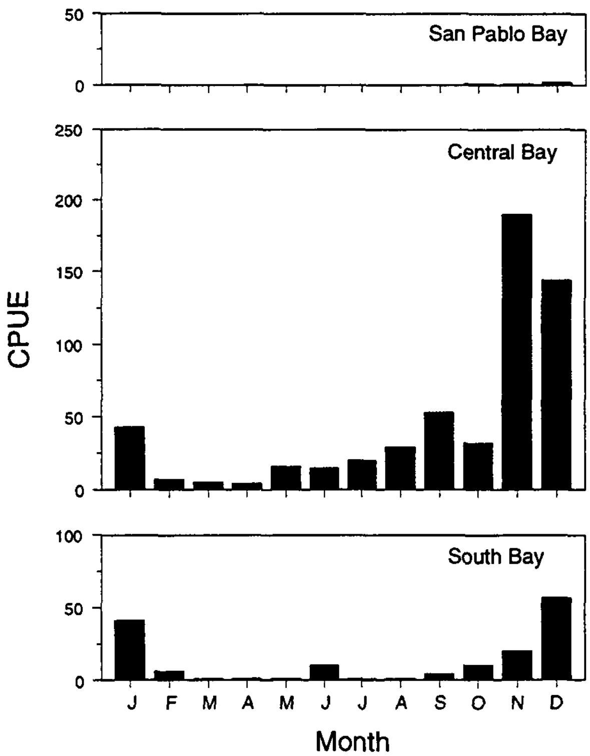

Figure 31 Monthly distribution (CPUE) of adult *C. nigromaculata* in 1996

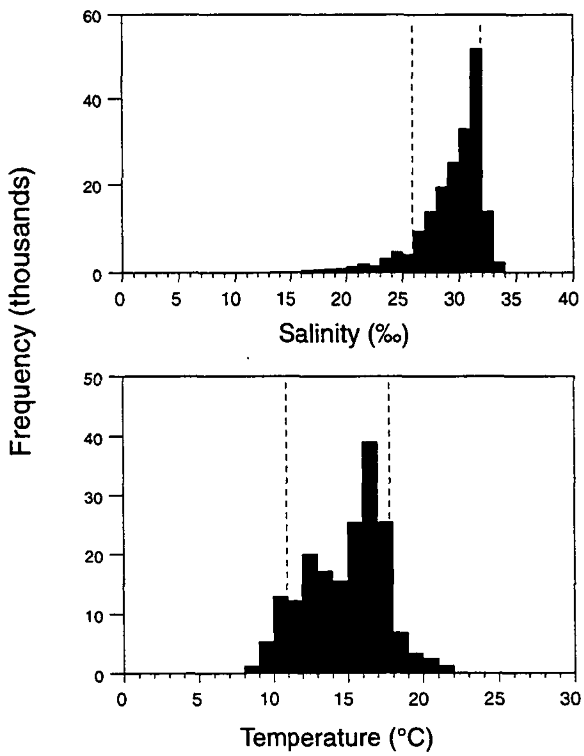

Figure 32 Salinity (‰) and temperature (°C) distributions of all sizes of *C. nigromaculata* collected with the otter trawl (1980 to 1996). Dashed vertical lines are the 10th and 90th percentiles.

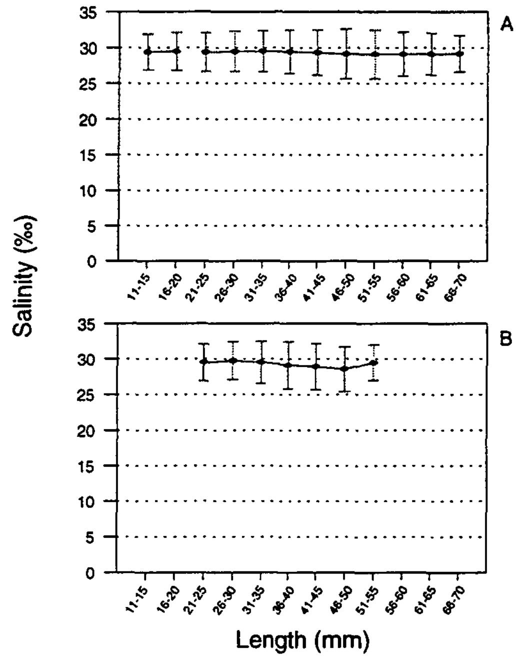

Figure 33 Mean salinity (±1 standard deviation) of *C. nigromaculata* by size class collected with the otter trawl: (A) juveniles (11 to 20 mm) and females and (B) males. Size classes are every 5 mm, from 11 to 70 mm.

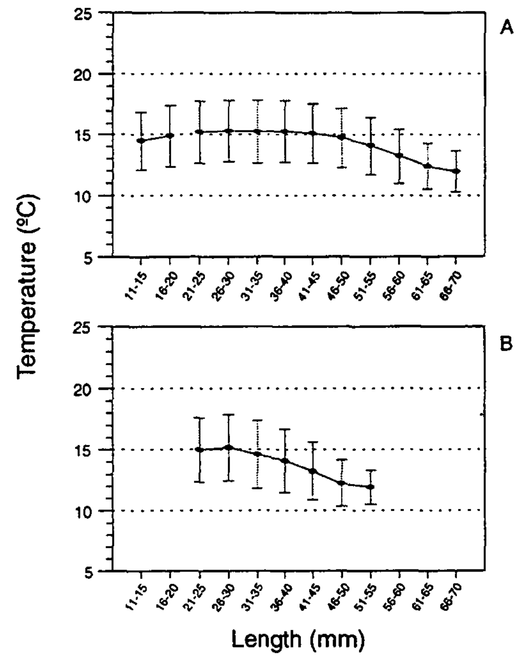

Figure 34 Mean temperature (±1 standard deviation) of *C. nigromaculata* by size class collected with the otter trawl: (A) juveniles (11 to 20 mm) and females and (B) males. Size classes are every 5 mm, from 11 to 70 mm.

Discussion

Crangon nigromaculata is generally limited to high salinity, cool areas of the San Francisco Estuary and based on collections by this study, City of San Francisco data, and Schmitt (1921) is more common in the nearshore coastal area than in the estuary itself. The estuary probably functions primarily as an expansion of the nearshore nursery area of *C. nigromaculata*, with juveniles opportunistically using the estuary when salinities and temperatures are appropriate. Juveniles dominated our catch and were collected at higher temperatures, but at essentially the same salinities as adults. Based on temperature preferences, juvenile *C. nigromaculata* are more tolerant of estuarine conditions than adults. The use of the estuary by juvenile *C. nigromaculata* was more sporadic than for either *C. franciscorum* or *C. nigricauda*, as abundance did not consistently peak during the same period each year, and multiple cohorts were common.

Early in the study, *C. nigromaculata* was a minor component of the estuary's shrimp community, but from 1990 through 1993, its abundance increased and it became the 3rd most common species collected overall. This increase in abundance is hypothesized to be a result of the 1987–1992 drought, as *C. nigromaculata* became well established in the higher salinity, cooler areas of the estuary in these years. But abundance remained relatively high through 1996, even during several years classified as either "above normal" or "wet." There may also be a relationship between increased ocean temperatures and abundance, as 2 of the most dramatic increases in abundance occurred in 1983 and 1993, concurrent with above average ocean temperatures (see Salinity and Temperature chapter, Figure 11). It is plausible that *C. nigromaculata* abundance would increase during warm ocean periods, as the San Francisco Estuary is near the northern limit of its range.

Crangon nigromaculata was most abundant in Central Bay in all years and seasons. The extension to South and San Pablo bays was usually limited to late fall through spring. This restricted distribution is supported by the salinity and temperature statistics, as only 10% were collected at salinities <25.9‰ or temperatures >17.8 °C. Although average bottom salinities in South and San Pablo bays were >26‰ for extended periods, especially during the drought (see Salinity and Temperature chapter, Figures 1 and 3), temperatures were >18 °C during the summer and early fall of all years in these embayments (see Salinity and Temperature chapter, Figures 8 and 10). In contrast, average Central Bay bottom salinities were >26‰ in many months and in all months from May 1987 through December 1992 (see Salinity and Temperature chapter, Figure 2). With a few exceptions, Central Bay temperatures were <18.0 °C in all months (see Salinity and Temperature chapter, Figure 9).

Palaemon macrodactylus

Palaemon macrodactylus, the oriental shrimp, was introduced to the San Francisco Estuary from Asia in the 1950s (Newman 1963) and is now common in lower salinity areas of the estuary, including South Bay below the Dumbarton Bridge (Kinnetic Laboratories 1987) and areas upstream of San Pablo Bay (Siegfried 1980, CDFG 1987). Few *P. macrodactylus* were collected by Siegfried (1980) at salinities <1‰. Most ovigerous *P. macrodactylus* were collected from May through August and many of the ovigerous females had ripe ovaries, indicating repeat reproduction. Based on the vertical distribution of larvae of an another species of Palaemonidae (Sandifer 1975), *P. macrodactylus* larvae have probably developed mechanisms that result in estuarine retention.

Methods

Palaemon macrodactylus were not separated into juvenile and adult categories for the abundance and distributional analyses, as a size of maturity is not available for males. But ovigerous and non-ovigerous categories were used for the seasonal abundance analyses. An index period of April through October was selected for the annual analyses and 1985 was selected as a representative year for the seasonal distribution analysis. The monthly length frequency histograms include all years and stations sampled. For salinity and temperature analyses, 5 mm groups by sex were used.

Results

Length Frequency

Female *P. macrodactylus* grow to a larger size than males; we collected males to 64 mm and females to 73 mm. There is some indication of 2 modes in the length frequency data through March, especially for males in February and March (Figure 35). Length data for both sexes were strongly unimodal from May through August, with a modal size of about 40 mm for males and about 55 mm for females in August. Another cohort of smaller shrimp, which are undoubtedly juveniles, made its first appearance in September. This cohort of smaller shrimp can be distinguished from the larger cohort through December, especially for males. Note that we collected very few small (<20 mm) *P. macrodactylus*; most shrimp <20 mm were collected from September through December.

Abundance

Palaemon macrodactylus was the 5th most common species of caridean shrimp collected from 1980 to 1996 and in some years ranked 3rd (see Table 1). The highest annual index of *P. macrodactylus* was in 1984 and the lowest indices were in 1983 and 1988 (Figure 36, Table 8). Abundance appears to have been somewhat cyclic in the 1980s, but there was less variation in the abundance indices in the 1990s.

Non-ovigerous *P. macrodactylus* were most abundant in the estuary from June through September (Figure 37, see Table 8). Abundance occasionally peaked outside of this period—the most notable occurrence was in January 1983 (see Table 8). Ovigerous females were most abundant from May through September, with few or none collected from November through March (see Figure 37).

Distribution

The center of distribution of *P. macrodactylus* was in either Suisun Bay or the west delta in every year (April through October) except 1983, when CPUE was highest in South Bay (Figure 38). There were annual shifts in distribution which were apparently associated with freshwater outflow. During years with high outflow (for example, 1982 and 1983), *P. macrodactylus* moved downstream, and few or no shrimp were collected in the west delta.

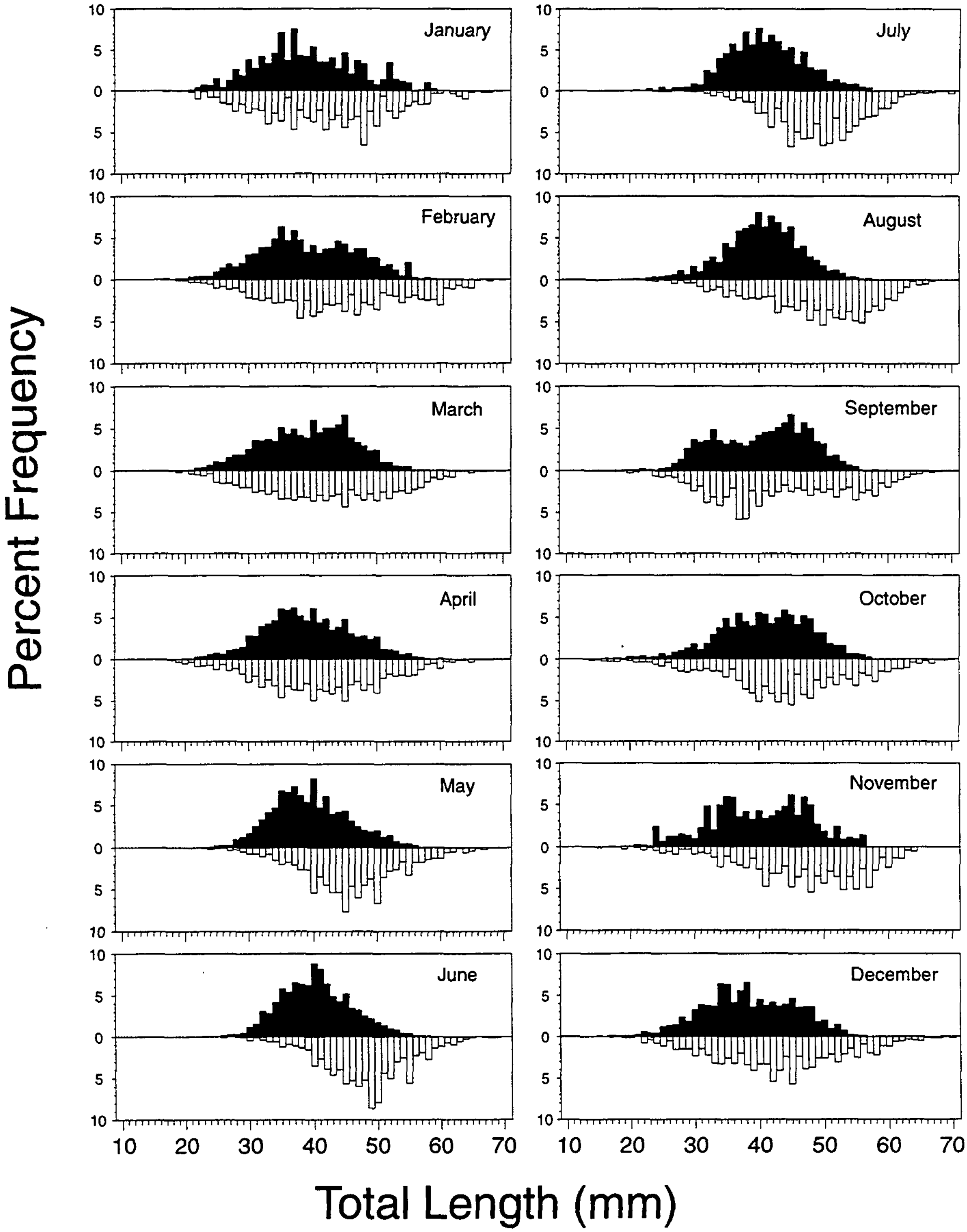

Figure 35 Monthly percent length frequencies of male (closed bars) and female (open bars) *P. macrodactylus* **collected with the otter trawl from 1980 to 1996.** Size classes are every 1 mm, from 11 to 70 mm.

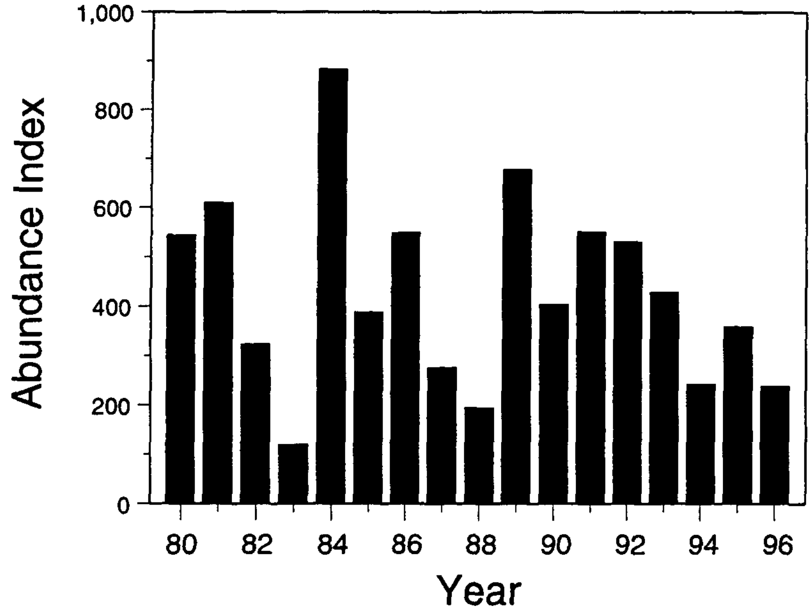

Figure 36 Annual abundance indices of *P. macrodactylus* collected with the otter trawl from 1980 to 1996. The index period is April to October and the indices are divided by 10.

Table 8 Monthly and annual abundance indices of all sizes of *P. macrodactylus* collected with the otter trawl from 1980 to 1996. The index period is April to October and the indices are divided by 10.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Apr–Oct*
1980		259	178	247	601	1154	794	384	387	230	138	145	543
1981	76	160	124	203	204	706	1264	798	462	625	198	315	609
1982	397	209	208	428	380	232	576	461	74	115	103	35	324
1983	488	224	94	137	130	340	97	72	17	37	23	184	119
1984	26	23	90	642	413	685	277	212	2622	1328	165	593	883
1985	245	557	227	167	417	386	475	488	449	328	71	330	387
1986	147	521	556	237	384	804	651	901	645	212	401	159	548
1987	88	63	186	233	254	226	310	487	308	113	150	181	276
1988	100	88	121	170	325	250	286	181	85	61	74	101	194
1989	70	100	113	488	602	1006	628	666					678
1990		66	235	281	364	620	614	455	288	199			403
1991		95	245	435	556	295	338	1667	284	274			550
1992		114	281	458	600	650	742	284	854	119			530
1993		277	288	616	309	281	724	614	388	62			428
1994		87	96	144	210	384	383	319	152	102			242
1995	108	200	520	116	786	391	389		316	158	91	80	359
1996	109	48	265	272	384	277	219	353	128	33	84	50	238
1981–1988, 1996	186	210	208	277	321	434	461	439	532	317	141	216	

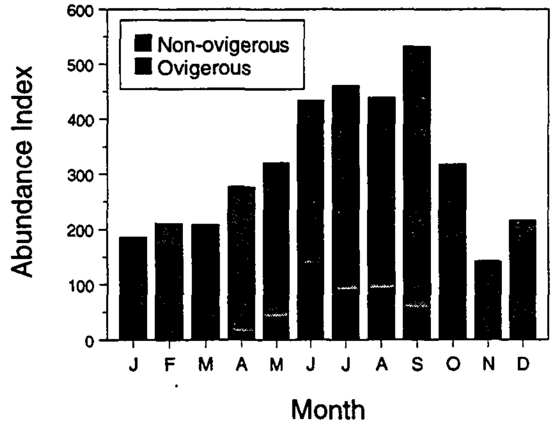

Figure 37 Monthly abundance indices of non-ovigerous and ovigerous *P. macrodactylus* collected with the otter trawl from 1981 to 1988 and 1996. The indices are divided by 10.

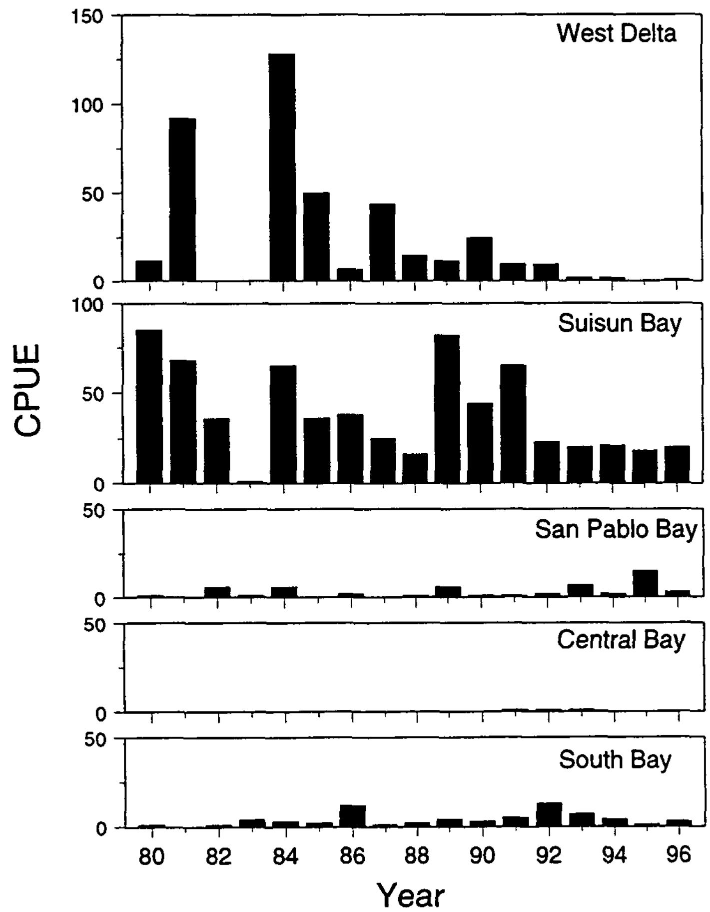

Figure 38 Annual distribution (CPUE) of all sizes of *P. macrodactylus* for April to October from 1980 to 1996

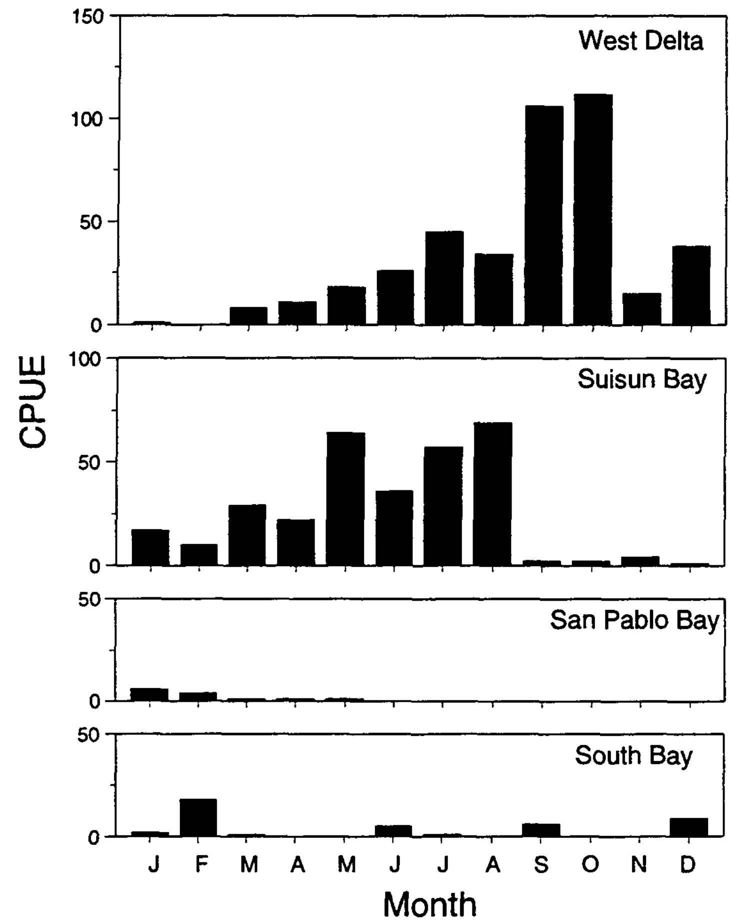

Figure 39 Monthly distribution (CPUE) of all sizes of *P. macrodactylus* collected with the otter trawl in 1985

Palaemon macrodactylus was concentrated in Suisun Bay from January through August (except for February, when CPUE was highest in South Bay), and the center of distribution shifted upstream to the west delta in September (Figure 39). This apparent distribution shift in fall was probably due to juvenile shrimp from the new cohort which either grew large enough to become catchable by the net or moved into the sampling area.

Salinity and Temperature

Palaemon macrodactylus was abundant over a very wide range of salinities and temperatures; 80% were collected from 1.9‰ to 28.1‰ and from 12.3 to 21.7 °C (10th and 90th percentiles, respectively, Figure 40). The mean salinity was 13.5‰ and the mean temperature was 18.0 °C.

The smallest size group (16 to 20 mm) was initially collected at a mean salinity of about 10‰ (Figures 41A and 41B). The mean salinity decreased with size, but more so for females than males. After 26 to 30 mm, salinity initially increased with size—the largest females (66 to 70 mm) were collected at a mean salinity of about 9‰ and the largest males (56 to 60 mm) were collected at a mean salinity of about 21‰. For any given size group, males were collected at a higher mean salinity than females.

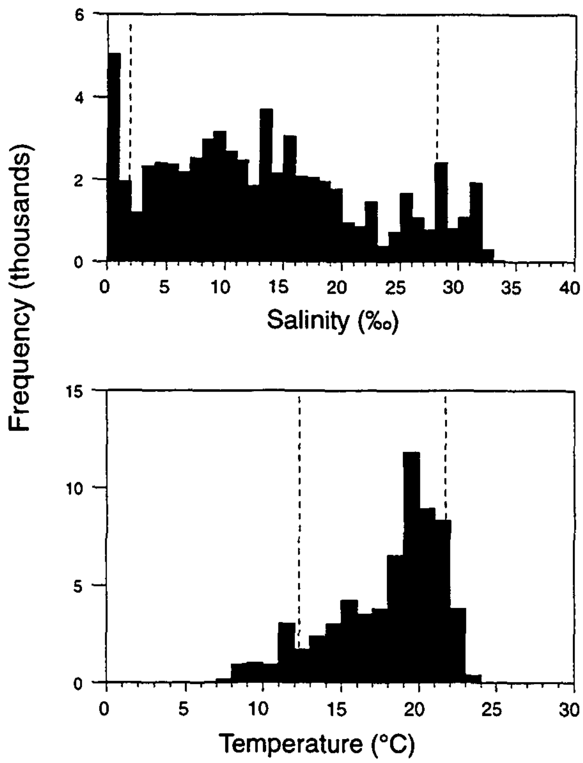

Figure 40 Salinity (‰) and temperature (°C) distributions of all sizes of *P. macrodactylus* collected with the otter trawl (1980 to 1996). Dashed vertical lines are the 10th and 90th percentiles.

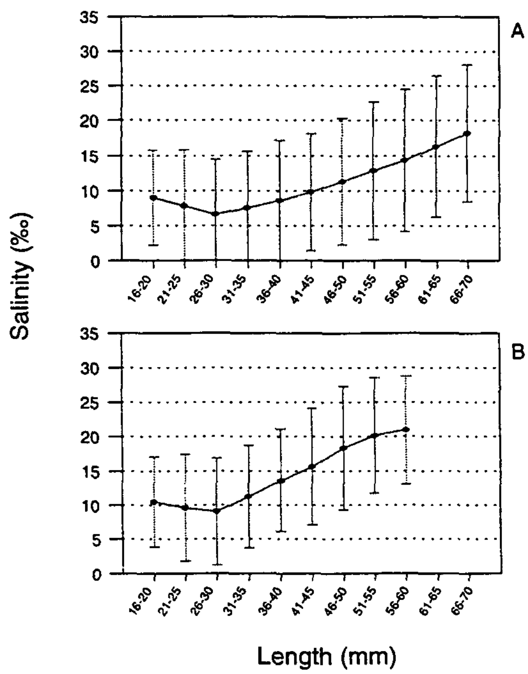

Figure 41 Mean salinity (±1 standard deviation) of *P. macrodactylus* by size class collected with the otter trawl: (A) females and (B) males. Size classes are every 5 mm, from 16 to 70 mm.

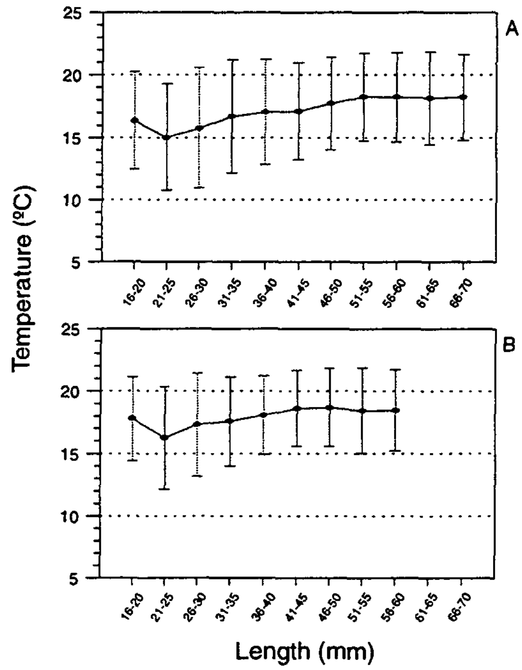

Figure 42 Mean temperature (±1 standard deviation) of *P. macrodactylus* by size class collected with the otter trawl: (A) females and (B) males. Size classes are every 5 mm, from 16 to 70 mm.

The mean temperature also initially decreased with size and them slowly increased (Figures 42A and 42B). Males were consistently collected at a higher mean temperature than females of the same size, up to 51 to 55 mm.

Discussion

Palaemon macrodactylus is an introduced species which apparently completes its entire life cycle in the estuary. It is well adapted to estuarine life, as it is abundant over a broader range of salinities and temperatures than any other species of caridean shrimp common to the estuary. Based on when ovigerous females were collected, most larvae hatch during the summer and early fall months when they are subject to the least amount of downstream transport by freshwater outflow. We collected few small juveniles in the otter trawl and hypothesize that they rear either in very shallow water areas or in tidal sloughs and creeks upstream of our sampling area.

Unlike *C. franciscorum*, *C. nigricauda*, and *C. nigromaculata*, *P. macrodactylus* abundance did not increase or decrease during the 1987–1992 drought. We may not have sampled a significant portion of the population, especially juveniles, during the drought and consequently the annual indices were biased low.

The distribution of *P. macrodactylus* shifted downstream in response to high outflow, but was never centered below Suisun Bay. There is also a population in the southern portion of South Bay, primarily south of the Dumbarton Bridge, which we evidently undersampled; some shrimp from this population were always collected, but accounted for a very small portion of the total index.

The initial, slight decrease in salinity and temperature with size is probably due to an upstream movement of juveniles and the collection of most juveniles in fall and winter, when salinities and temperatures decrease. An increase in salinity and temperature with size has been reported for other species of estuarine shrimp and is indicative of a downstream movement of maturing shrimp to higher salinities for reproduction. Male *P. macrodactylus* were collected at higher salinities and lower temperatures than females. This pattern has also been reported for *C. franciscorum* and *C. nigricauda* and is consistent with the observation that males of many species of caridean shrimp are distributed downstream of females.

Heptacarpus stimpsoni

Heptacarpus stimpsoni, Stimpson's coastal shrimp, ranges from Sheep Bay, Alaska, to Punta Abreojos, Baja California (Jensen 1995). It is common subtidally in eelgrass beds and in macroalgae (Smith and Carlton 1975) but also occurs on soft bottoms (Jensen 1995). It has been collected from the intertidal to 73 m (Jensen 1995). *Heptacarpus stimpsoni* was the most common member of the family Hippolytidae collected in San Francisco Bay by Schmitt (1921). In his collections it was abundant in Central and South bays and was only occasionally collected in lower San Pablo Bay. This is a relatively small species, with a maximum size of 32 mm (Jensen 1995).

Methods

Heptacarpus stimpsoni was not separated into juvenile and adult categories for the abundance and distributional analyses, because a size of maturity is not known for males. Also, after March 1987, *Heptacarpus* were no longer sexed and measured, but categorized as either ovigerous or non-ovigerous and counted. These ovigerous and non-ovigerous categories were used for the seasonal abundance analyses. An index period of February through October was selected for the annual analyses. For analysis of seasonal distribution, 1987 was selected as a representative year. The 1981 to 1986 length frequency data were used for the monthly length frequency histograms.

Results

Length and Length Frequency

The largest *H. stimpsoni* female collected was 35 mm and the largest male 32 mm. The smallest shrimp (<10 to 15 mm) were collected primarily in December and January and from May through August (Figure 43). Most large shrimp (>30 mm) were collected from December through February and in June. The maximum modal length of about 28 mm occurred in February.

Abundance

Heptacarpus stimpsoni was the 4th most common species of caridean shrimp collected over the study period; in 1989 it ranked 3rd and in 1984 and 1985 it ranked 5th (see Table 1). The annual abundance indices of *H. stimpsoni* were very low from 1980 thorough 1986, increased from 1987 to 1991, and, except for 1995, remained at relatively high levels through 1996 (Figure 44, Table 9). Ovigerous females comprised a very high proportion of the annual index, ranging from 33% in 1983 to 64% in 1984 (see Figure 44, Table 10).

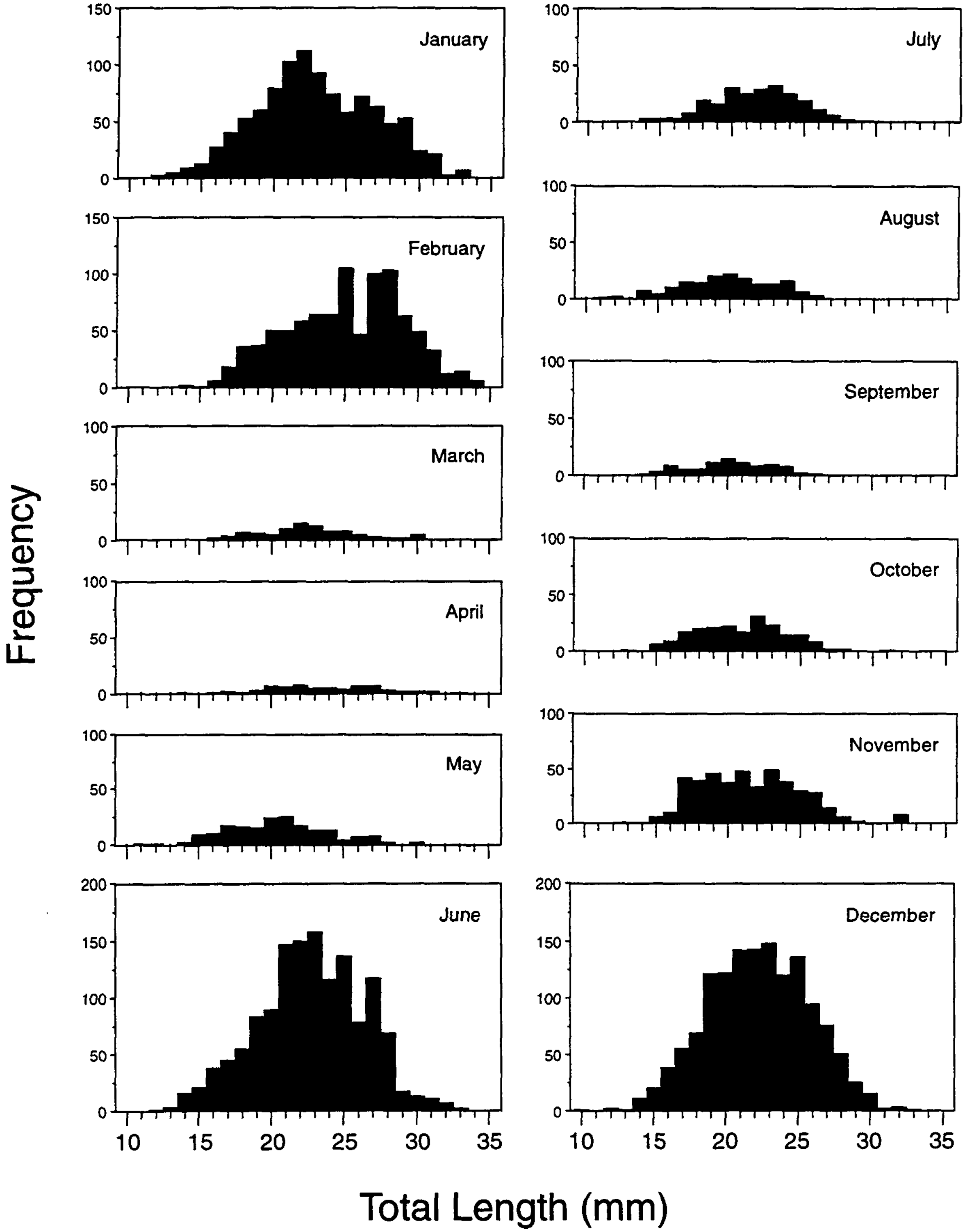

Figure 43 Monthly length-frequency histograms for male and female *H. stimpsoni* **combined from 1981 to 1986.** Size classes are every 1 mm, from 10 to 35 mm.

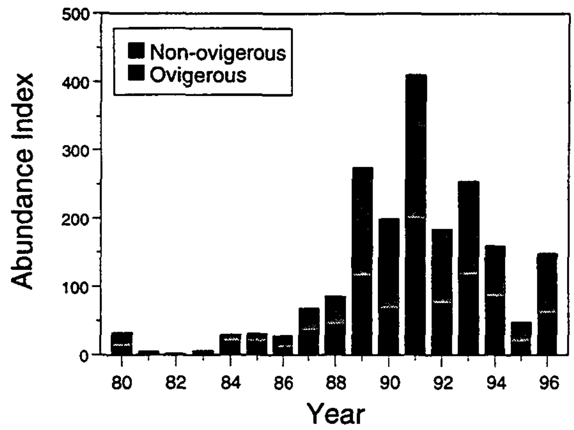

Figure 44 Annual abundance indices of ovigerous and non-ovigerous *H. stimpsoni* collected with the otter trawl from 1980 to 1996. The index period is February to October and the indices are divided by 10.

Table 9 Monthly and annual abundance indices of all sizes of *H. stimpsoni* collected with the otter trawl from 1980 to 1996. The index period is February to October and the indices are divided by 10.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		197	33	1	10	40	7	1	0	0	0	2	32
1981	60	7	13	1	8	1	4	1	3	10	0	65	5
1982	49	1	1	0	3	2	0	0	7	0	37	122	2
1983	118	16	0	0	0	0	2	14	3	22	40	68	6
1984	3	4	7	15	37	208	2	3	1	0	1	14	31
1985	42	158	5	3	1	82	16	0	2	8	14	60	31
1986	30	78	2	0	3	80	44	26	9	18	30	82	29
1987	54	128	83	13	8	29	24	46	124	159	230	362	68
1988	252	65	94	244	96	91	74	39	55	15	53	100	86
1989	71	83	74	709	313	491	102	147					274
1990		121	258	105	122	236	275	180	251	244			199
1991		388	688	466	378	554	161	385	162	521			411
1992		425	414	79	235	163	37	26	127	158			185
1993		757	299	253	193	334	351	68	5	28			254
1994		105	102	44	143	445	169	190	176	60			159
1995	222	140	146	1	6	68	4		5	10	68	348	47
1996	342	223	108	85	182	165	160	266	77	75	288	418	149
1981–1988, 1996	106	75	35	40	38	73	36	44	31	34	77	144	

Table 10 Annual abundance indices of ovigerous, non-ovigerous, and percent ovigerous *H. stimpsoni* collected the otter trawl from 1980 to 1996. The index period is February to October and the indices are divided by 10.

Year	*Ovigerous*	*Non-ovigerous*	*Percent Ovigerous*
1980	11	21	34.4
1981	2	3	40.0
1982	1	1	50.0
1983	2	4	33.3
1984	19	11	63.3
1985	18	13	58.1
1986	10	18	35.7
1987	35	33	51.5
1988	44	42	51.2
1989	115	159	42.0
1990	67	132	33.7
1991	199	212	48.4
1992	75	109	40.8
1993	116	138	45.7
1994	85	74	53.5
1995	18	30	37.5
1996	60	88	40.5

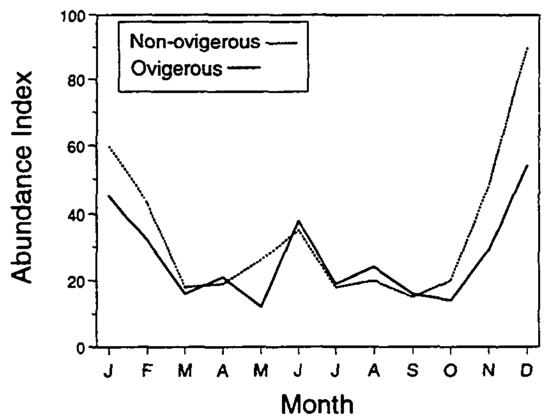

Figure 45 Monthly abundance indices of non-ovigerous and ovigerous *H. stimpsoni* collected with the otter trawl from 1981 to 1988 and in 1996. The indices are divided by 10.

Heptacarpus stimpsoni was most abundant from November through February with a smaller peak in June (Figure 45). The ovigerous and non-ovigerous trends were almost identical. In years we sampled for 12 months, a summer peak occurred in 1980, 1984, 1985, 1986, and 1996 (see Table 9). The winter peak was very small relative to the summer peak in 1984.

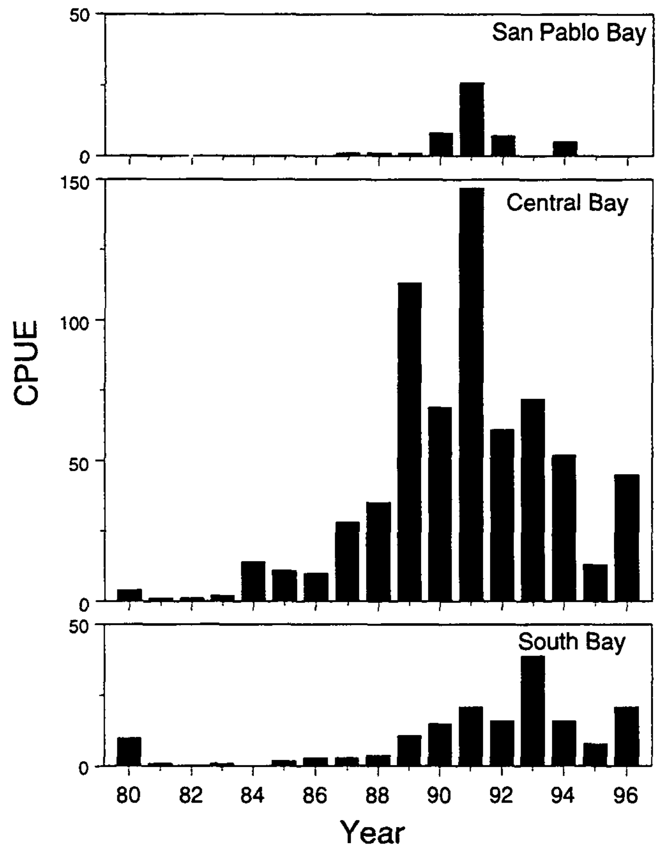

Figure 46 Annual distribution (CPUE) of all sizes of *H. stimpsoni* for February to October from 1980 to 1996

Distribution

The center of distribution of *H. stimpsoni* was in Central Bay in all years except 1980, when CPUE was highest in South Bay (Figure 46). Distribution expanded to San Pablo Bay primarily during the 1987–1992 drought. When *H. stimpsoni* was collected in San Pablo Bay, it was usually at the downstream stations. Although not apparent on the distribution graph, a few *H. stimpsoni* were collected in Carquinez Strait. Most of these collections were in the fall and spring of 1990, 1991, and 1992.

Heptacarpus stimpsoni was also concentrated in Central Bay all months, although the South and Central Bay CPUEs were almost equal in December (Figure 47). Central Bay CPUE was relatively high in fall, but *H. stimpsoni* typically did not expand its distribution to South or San Pablo bays until December.

Salinity and Temperature

Heptacarpus stimpsoni was collected at relatively high salinities and low temperatures, with 80% from 24.1‰ to 31.8‰ and 10.9 to 18.0 °C (10th and 90th percentiles, respectively, Figure 48). It was collected at a mean salinity of 28.7‰ and a mean temperature of 14.4 °C.

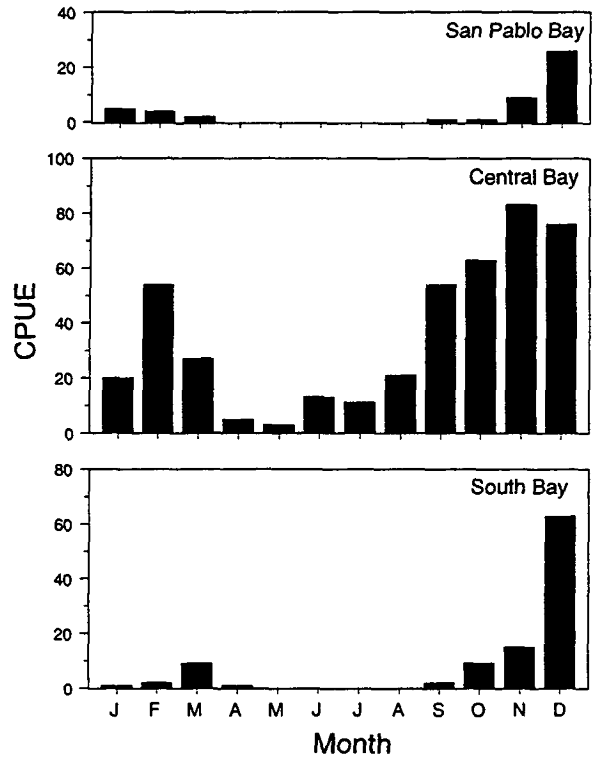

Figure 47 Monthly distribution (CPUE) of all sizes of *H. stimpsoni* in 1987

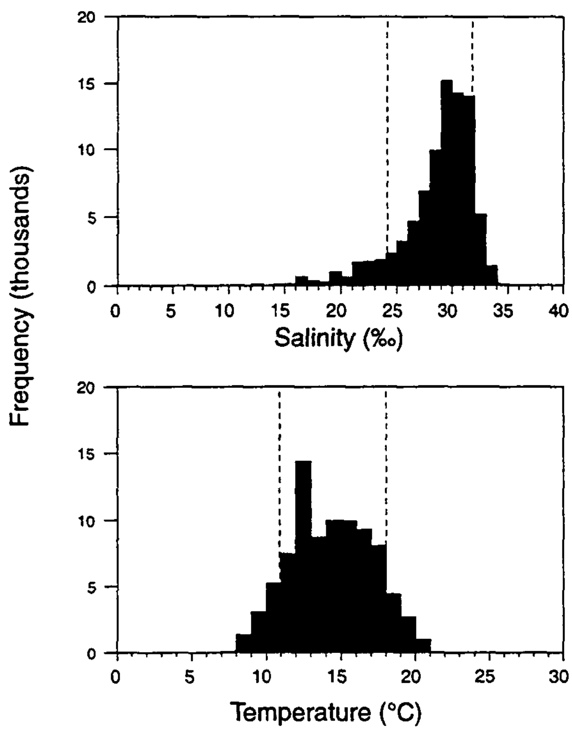

Figure 48 Salinity (‰) and temperature (°C) distributions of all sizes of *H. stimpsoni* collected with the otter trawl (1980 to 1996). Dashed vertical lines are the 10th and 90th percentiles.

Discussion

Heptacarpus stimpsoni is most common in cool, polyhaline to euhaline waters and is generally limited to South, Central, and lower San Pablo bays. It moved upstream during periods of low outflow, when higher salinities prevailed, and often during winter, when temperatures were cooler. Not surprisingly, the abundance of *H. stimpsoni* increased during the drought, with the highest abundance index in 1991. As for *C. nigricauda* and *C. nigromaculata*, abundance remained relatively high after the drought ended, in spite of some very high outflows.

Winter appears to be the major reproductive period of *H. stimpsoni*, with a 2nd, smaller reproductive period in summer. The peak abundance of ovigerous shrimp closely corresponds to the peak of non-ovigerous shrimp, indicating that a majority of the non-ovigerous shrimp we collected were adults. Any bias towards adults is probably due to the mesh selectivity of our gear—we rarely collected shrimp <10 mm in the otter trawl, which would exclude many juvenile *H. stimpsoni*. The high percentage of ovigerous females collected is notable, but is also probably due to a bias towards adult *H. stimpsoni* in our collections.

The relatively low abundance from March through October may also be due size selectivity of the gear. If peak reproductive activity is in winter, peak recruitment of juveniles would be in spring and summer. Many of these juveniles would not be collected by the otter trawl due to their small size. Alternatively, *H. stimpsoni* may emigrate from the estuary in late winter and remain in the nearshore ocean area until fall. However, there is no data from the Gulf of the Farallones or other nearshore ocean areas that supports such a migration.

Lissocrangon stylirostris

Lissocrangon stylirostris, the smooth bay shrimp, ranges from Chirikof Island, Alaska, to San Luis Obispo, California (Jensen 1995). It is common in the surf zone of relatively high energy sandy beaches and on sand or rock and sand bottoms subtidally and has been collected to 80 m (Jensen 1995). In an early survey of San Francisco Bay, *L. stylirostris* was collected from hard or sandy bottoms from Central Bay and lower San Pablo Bay, below Point San Pedro (Schmitt 1921). The largest reported size is 61 mm (Jensen 1995).

Methods

Lissocrangon stylirostris was not separated into juvenile and adult categories for the abundance and distributional analyses, because a size of maturity is not known for males. But ovigerous and non-ovigerous categories were used for the seasonal abundance analyses. An index period of February through October was selected for the annual analyses. No distributional figures are presented, as distribution rarely varied by year or season. The monthly length frequency histograms include all years and stations sampled, but the sexes were not plotted separately because so few males were collected. All sizes and both sexes were combined for the salinity and temperature analyses.

Results

Length Frequency

The size distribution of *L. stylirostris* was bimodal from January through March, with modal lengths of about 35 and 40 mm (Figure 49). The larger mode was detectable through June, when a large number of juvenile shrimp were also first collected. It is possible that several other cohorts entered the estuary during summer, as several modes were visible in the length frequency distributions in most months from August through December. Alternatively, the larger-sized mode could be females, which would be expected to grow more rapidly than males. In June, the modal length of juvenile shrimp was about 18 mm and by December it was 37 mm. Although the size of maturity is not reported in the literature, the smallest ovigerous female we collected was 29 mm and it appears that females are mature at about 33 mm, as <1% of the ovigerous females were <33 mm.

Abundance

Lissocrangon stylirostris was the 6th most common species of caridean shrimp collected from 1980 to 1996 by the Bay Study, and ranked 5th in 1984 (see Table 1). No *L. stylirostris* were collected (or recorded) in 1980 and 1981 and very few in 1982 and 1983. The highest annual abundance index was in 1986, followed by 1984 and 1996 (Figure 50, Table 11). Abundance appears to have been cyclic, with very low indices from 1988 through 1992. Juvenile *L. stylirostris* were estimated to comprise 68% of the total catch (this estimate is based on approximate sizes of maturity of 28 mm for males and 33 mm for females).

Abundance of *L. stylirostris* peaked from July to September, declined slowly through March, and was very low from April through June (Figure 51, see Table 11). The highest abundance of ovigerous females was from January through June, and the ovigerous index was slightly higher than the non-ovigerous index in April and May.

Distribution

Lissocrangon stylirostris was limited to Central Bay and the lower channel stations in San Pablo Bay. Most were collected at channel stations; 6,544 or 85% came from station #213 (Alcatraz Island), which has a rock-sand substrate. There may be a seasonal movement to San Pablo Bay in fall and winter, since the few *L. stylirostris* collected there were present from October through January.

Salinity and Temperature

Lissocrangon stylirostris was collected at relatively high salinities and low temperatures, with the majority collected from 25.4‰ to 33.6‰ and 11.8 to 16.6 °C (10th and 90th percentiles, respectively, Figure 52). The mean salinity was 30.2‰ and the mean temperature was 14.7 °C.

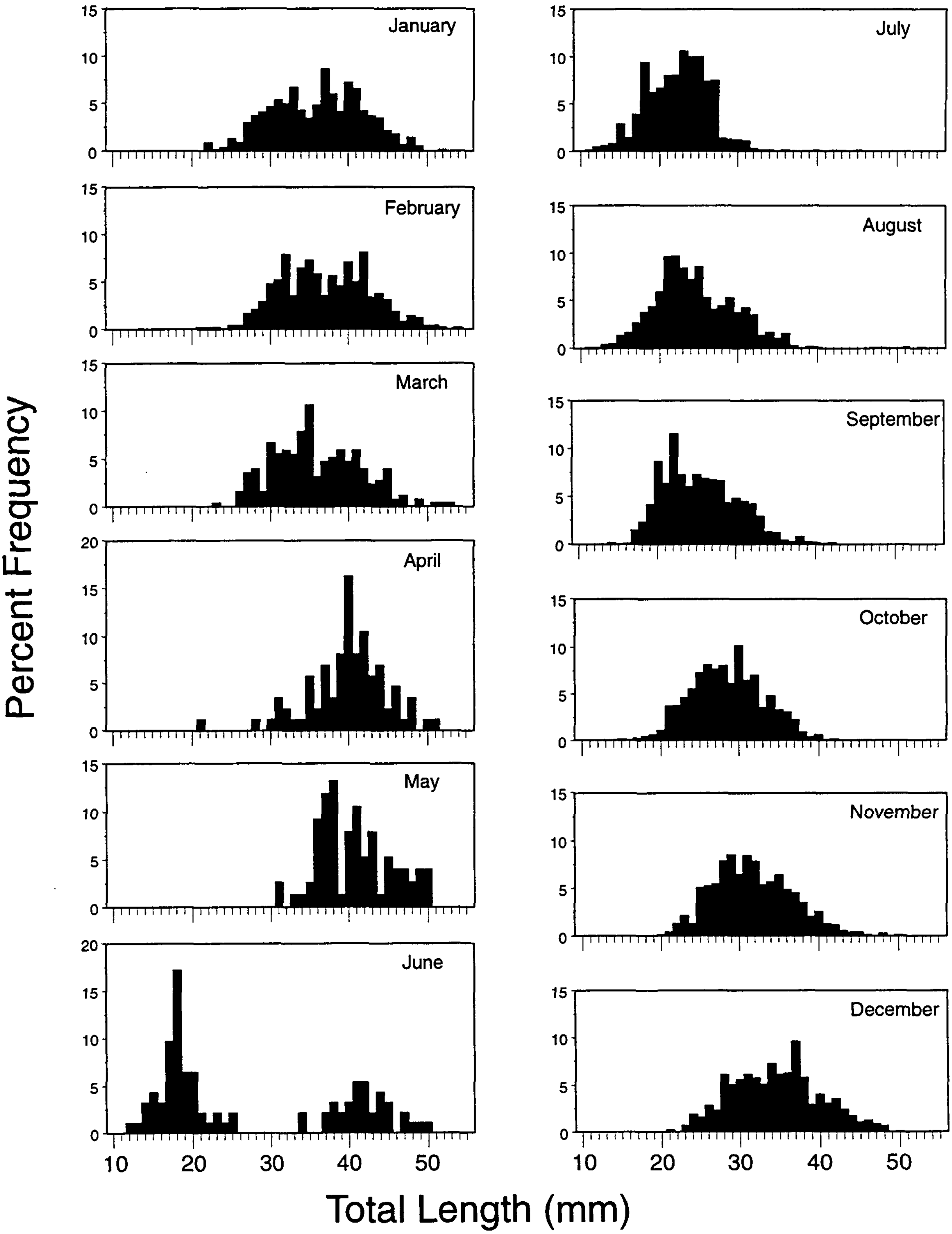

Figure 49 Monthly percent length-frequency histograms for male and female *L. stylirostris* **combined from 1980 to 1996.** Size classes are every 1 mm, from 11 to 55 mm.

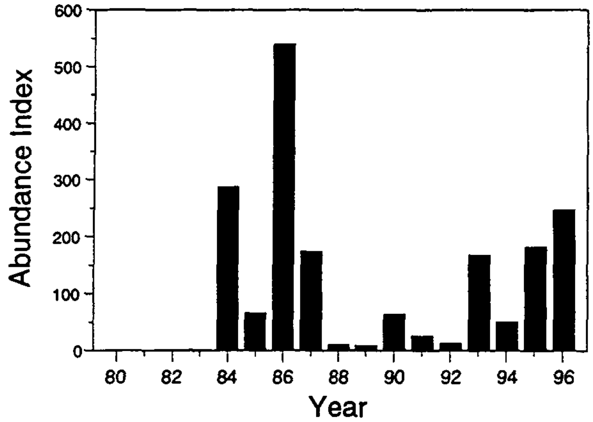

Figure 50 Annual abundance indices *L. stylirostris* collected with the otter trawl from 1980 to 1996. The index period is February to October and the indices are divided by 10.

Table 11 Monthly and annual abundance indices of all sizes of *L. stylirostris* collected with the otter trawl from 1980 to 1996. The index period is February to October and the indices are divided by 10.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0	0	0	3	0
1983	0	0	0	5	0	0	0	0	0	0	0	0	1
1984	352	60	224	22	70	65	381	1395	251	111	303	133	287
1985	165	41	54	5	16	0	0	330	97	57	62	73	67
1986	235	138	89	24	8	135	1570	1712	584	600	589	189	540
1987	297	222	57	16	0	0	8	189	733	337	227	260	174
1988	105	14	30	0	0	11	5	5	24	11	11	61	11
1989	27	0	32	14	8	3	3	3					9
1990		65	32	0	0	0	0	57	114	311			64
1991		24	22	22	11	0	3	46	49	60			26
1992		87	5	16	0	0	0	0	0	8			13
1993		192	70	5	5	24	192	525	251	246			168
1994		95	19	68	32	3	5	65	146	24			51
1995	268	176	11	38	54	3	206		811	168	430	354	183
1996	38	187	38	0	0	8	108	384	1241	257	233	227	247
1981–1988, 1996	132	73	55	8	11	24	230	446	326	153	158	105	

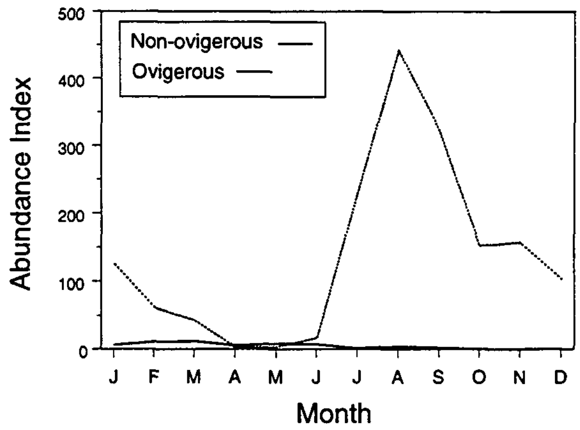

Figure 51 Monthly abundance indices of non-ovigerous and ovigerous *L. stylirostris* collected with the otter trawl from 1981 to 1988 and in 1996. The indices are divided by 10.

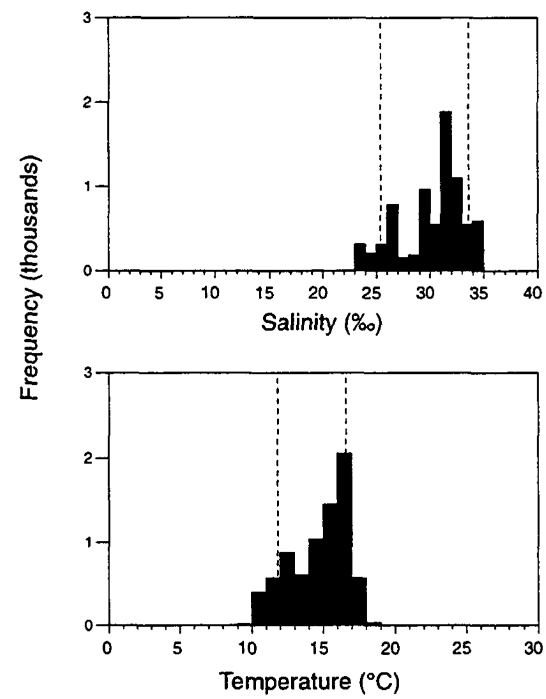

Figure 52 Salinity (‰) and temperature (°C) distributions of all sizes of *L. stylirostris* collected with the otter trawl (1980 to 1996). Dashed vertical lines are the 10th and 90th percentiles.

Discussion

Lissocrangon stylirostris is a minor component of the San Francisco Estuary's shrimp community, usually ranking 6th in total catch. It is limited to cool, high salinity areas and was rarely collected outside of Central Bay. Based on the peak abundance of juveniles and ovigerous females, larval hatching occurs in spring. As relatively few ovigerous females were collected, the reproductive population is probably concentrated in the nearshore ocean area. Although the estuary does serve as a nursery area for *L. stylirostris*, it appears that it is primarily an extension of the ocean habitat for both juveniles and adults.

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Notes

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